MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. LII.

SESSION 1877-78.—PART II.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

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CONTENTS.

SECT. I.—MINUTES OF PROCEEDINGS.

SECT. II.—OTHER SELECTED PAPERS.

SECT. III.—ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

ERRATA.

Vol. xlv., p. 267, line 6 from bottom, after "73·8 *feet*" add "*per second.*"
" " p. 268, line 16 from bottom, after "61·87 feet" add "*per second.*"
" " p. 269, line 19, for "65 feet *per minute*" read "63·16 feet *per second.*"
" xlvii., p. 327, line 19, and p. 332, line 32, for a gauge of "3 feet 7½ inches" read "3 feet 6 inches."

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1877-78.—PART II.

SECT. I.—MINUTES OF PROCEEDINGS.

January 15, 1878.

JOHN FREDERIC BATEMAN, F.R.SS. L. & E., President, in the Chair.

THE following Candidates were balloted for and duly elected:—COSMO INNES, GEORGE STANTON PROVIS, and DAVID MONRO WESTLAND, as Members; and GEORGE DUNDAS CHURCHWARD, Stud. Inst. C.E., JOHN JAMES HENDERSON, FRANKLIN HILTON, JOHN LAKEMAN HODGE, EDWARD HODGES, RICHARD JACQUES, ANDREW JAMIESON, JOHN FREDERICK LEWIS JETTER, B.A., HARRY ROBERT KEMPE, Stud. Inst. C.E., HENRY OLIVER, HENRY PEACEY, Stud. Inst. C.E., THOMAS BAWDEN PROVIS, WILLIAM HENRY VENABLES, and WILLIAM WEAVER, as Associates.

It was announced that the Council, acting under the provisions of Sect. III., Cl. 8, of the Bye-Laws, had transferred PHILIP BARRY, THOMAS CARRINGTON, ALFRED CHAPMAN, JAMES GREGSON CHAPMAN, RICHARD GEORGE COKE, WILLIAM DEAN, JOSEPH EDWARD FISHER, GEORGE FOWLER, CHARLES BROWNE GOLDSON, M.A., CHARLES FOOTE GOWER, JABEZ JAMES, EDWARD JOHN LLOYD, WALTER HENRY MAUDSLAY, WILLIAM MORRIS (Deptford), WILLIAM MORRIS (Westminster), GEORGE GORDON PAGE, WILLIAM EDMUND RICH, CHARLES SELLS, DAVID THOMSON, and FRANK NAPIER THOROWGOOD, from the class of Associate to that of Member.

Also that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions

of Sect. IV. of the Bye-Laws, as Students of the Institution:—JOHN FRANCIS ALBRIGHT, ALBERT FRANÇOIS LOUIS ALLIMAN, CHARLES HENRY BARRATT, WILLIAM HENRY BARRETT, JAMES TREMBATH BOASE, REGINALD PELHAM BOLTON, ALFRED BOX, JOSEPH PRENDERGAST COY, ALEXANDER STEWART FORBES, ERNEST HALL HEDLEY, WILLIAM INGLIS, GEORGE LLOYD, JOSEPH WILLIAM PARRY, FREDERICK REILLY, RICHARD COTTON ROWLEY, DUKINFIELD HENRY SCOTT, ARTHUR SACKVILLE THOMSON, AUGUSTUS WORTHINGTON TOPP, CHARLES ARROWSMITH WALSH, THOMAS HENRY WILLIAMS, and OTWAY EDWARD WOODHOUSE.

Mr. BATEMAN addressed the Meeting in the following terms, on taking the chair for the first time, after his election as President:—

THE duty of addressing the Institution becomes constantly more difficult on each election of a President. Nearly every subject which can be supposed to be of interest to the profession has been treated by my predecessors.

The Society was established in 1818 by five devoted men, only one of whom still survives. In 1828 a Royal Charter was obtained, incorporating the Society under the presidency of Mr. Telford, who retained the office till his death in 1834. On his decease, Mr. James Walker was elected President, and, after ably contributing to the growing influence of the Institution, he resigned the post in 1845, having held it for ten years. The addresses of these two gentlemen were such as befitted an infant Institution struggling into importance, and gradually assuming a position which is now at once the pride of the members and the admiration of the world. They were addresses pregnant with sound advice and great encouragement. When Mr. Walker resigned, the numbers were as follows:—

Honorary Members	35
Members	177
Associates	285
Graduates	55
Total	552

They are now:—

Honorary Members	16
Members	979
Associates	1,701
Students	493
Total	3,189

Mr. Walker was succeeded by Sir John Rennie, who held the distinguished position for three years. Since his retirement from the office, a new President has been elected every two years; and I need hardly say that they have all been amongst the most distinguished members of the profession.

Since Mr. Walker's time, there have been sixteen different Presidents, and as many addresses. Most of these have been principally statements of the various important engineering works executed in different parts of the world during the preceding two years, and observations on the existing position of the profession, but some have exhibited a distinctive character. Thus, Sir John Rennie in 1846, gave a condensed history of engineering up to that date. This is now thirty-two years ago, during which period, the progress of the profession and of the construction of works of utility have exceeded all previous anticipation. No more beneficial service could be rendered than a continuation of that history to the present period, but neither time nor information will enable me to perform the task.

Mr. Stephenson in 1856 summarized the statistics of English railways to that time; and Mr. Locke followed with a description of those in France.

Mr. (now Sir John) Hawkshaw alluded briefly to the electric telegraph, to the speed of steamers, to armour-plated ships, to gunnery, and to iron cylinders as foundations for bridges.

Mr. McClean dwelt on the material prosperity of the country which had been produced by the construction of public works, especially railways.

Mr. Fowler, in 1866, offered some admirable remarks on the education of Engineers.

Mr. Gregory principally devoted himself to military engineering, to gunnery, armour-plating, steamers, and railways for military purposes.

Mr. Vignoles, in 1870, gave an interesting and instructive history of ancient engineering, particularly of early hydraulic engineering, and then a tolerably complete statement of engineering education as pursued in France, and concluded by many amusing incidents of his early professional life.

These are but a few of the able addresses which have been delivered; and in omitting allusion to others, it is not because I think them in any degree inferior to those I have mentioned, but because they are not quite of such a distinctive character.

It will thus be seen that nearly every subject which comes within the range of the profession has already been dealt with; some

perhaps hardly to the extent which their importance demands; and most are capable of further elucidation by the rapid progress which has been made in every branch of the profession, and by the enormous extension of engineering works in all parts of the world.

When Mr. Stephenson described the railways in Great Britain and Ireland in 1856, he stated that the sum authorized by Parliament to be raised for railway works amounted at the end of 1854 to £368,000,000, of which £286,000,000 had actually been raised.

Now, from official railway returns, it appears that the amount of capital authorized for the construction of railways in the United Kingdom up to the 31st of December, 1876, was £741,802,322, of which there had been actually raised £682,085,851 sterling, considerably more than double the amount in Mr. Stephenson's time.

At the end of 1856, Mr. Locke stated that the length of railways in France for which concessions had been granted was 7,030 miles, of which 4,060 miles had been opened. Now—or rather at the beginning of 1877—the length of lines in France opened to the public was 12,715 miles, besides which 3,737 miles were in course of construction or had been authorised by concessions, making a total of 16,452 miles, also considerably more than double what it was at the time of Mr. Locke's address.

All this and much more has been done in engineering work since the time when Mr. Telford told our ex-President, Mr. Harrison, that he had made a great mistake in choosing Civil Engineering for a profession, for there was nothing to do, and the sooner he turned his attention to something else the better.

Mr. McClean referred to the great increase in the prosperity of the country which had resulted from the introduction and extension of railways. His address was delivered in January 1864, and he compares the year 1815, before the great extension of engineering works, with 1856, just forty years subsequently, and after railways had greatly developed the resources of the country. He showed that the income available for taxation derived from land had not increased, while that from houses had increased nearly 300 per cent., and the net profits from mines, quarries, ironworks, canals, railways, &c., had increased upwards of 1,200 per cent. The net profits he stated at upwards of £18,000,000.

Since the year 1856, the increase has been very great. It is difficult however to compare amounts, in consequence of a difference in the mode of arrangement; but I may mention that, for the year ending

31st March, 1876, the assessment on quarries, mines, ironworks, gasworks, waterworks, canals, fishings, and market-tolls, being a portion only of what was included in Mr. McClean's £18,000,000, amounted to £28,840,851; the assessment on railways in the United Kingdom to £26,215,203; and the gross assessment on the investments mentioned by Mr. McClean to £92,636,312.

Mr. McClean also referred to the production of coal and iron, and other minerals. The production has enormously increased since his address. The quantity of coal exported to foreign countries is now between 14,000,000 and 15,000,000 tons per annum, and its declared value nearly £10,000,000 sterling. The coals brought to London alone by railway, canal, and sea, exceed 8,000,000 tons, and the gross production of the United Kingdom is nearly 132,000,000 tons per annum.

These few general remarks will show how largely the engineer has been employed, and how much his labours have contributed to the development of the wealth and prosperity of every country in which they have been carried on.

I will now proceed to matters of more personal interest to each member of the Institution.

There is considerable individuality in the practice of most of our members. Circumstances to a great extent control our operations. Early engagements or opportunities do much towards fixing a man's future career. Some men have been principally engaged in the construction of railways, others in hydraulic engineering, many in mechanical construction. Some have devoted their energies to the development of the electric telegraph; others to gas-lighting, to armour-plating, to naval architecture, or to artillery; while not a few may be considered as purely scientific men, investigating the strength of materials, the laws of motion, the phenomena of light and heat, and the thousand other questions which have a bearing on practical engineering.

It is, in fact, the combination of theory and practice which makes the successful engineer. Engineering is but the embodiment of practical wisdom,—"the conjunction," as Bacon calls it, "of contemplation and action."

It was thought, combined with practice, which enabled Watt to perfect his invention of the steam engine, now little more than one hundred years ago. It was thought and practice which, in the hands of George Stephenson, led to the successful application of the locomotive engine. Thought and practice produced the electric telegraph. Indeed, though practical wisdom may be said to be the

parent of almost all successful undertakings, it is especially due to the combination of sound theory with successful practice, and to the practical wisdom which is the result, that engineering owes its present high position, and has been able to contribute so largely to the material prosperity of the world. It is not, however, material prosperity only to which the engineer may lay claim. His works have carried civilisation into the most remote and barbarous regions. The steam engine, in its various applications, has knitted together the most distant nations; it has brought ignorance into contact with knowledge, heathenism with Christianity, and has extended the blessings of civilisation to every quarter of the globe.

Looking at what has been done before, and following the example of my distinguished predecessors, I will endeavour to give a brief description of some of the more important works executed during the last two years, and then advert to the peculiarities of that branch of the profession to which my attention has been more particularly directed. I do this in the conviction that the experience of a special kind, gained during a long professional life, is really of more value than allusion, however lucid, to those subjects which one only imperfectly understands, and on which, many of those I am now addressing could give much more information than I am able to impart.

But there is one subject which I must not pass over, namely, the education of the engineer. I do not, however, intend to enlarge on this question, as if I were a tutor addressing students, for there are many men in this assembly quite as experienced as myself, and probably possessing much more information; nor could I hope to add anything of value to the observations and suggestions of my predecessor Mr. Fowler.

It is, however, due to the Council to say that subsequent to his address, namely, from 1867 to 1869, they obtained from every part of the world a great deal of most valuable information on "The Education and Status of Civil Engineers in the United Kingdom and in Foreign Countries." This information was compiled by our Member of Council, Dr. Pole, F.R.S., from documents supplied to the Council, and published in a separate volume in 1870, which has been circulated amongst the Members and Associates of that date.

The information thus acquired was asked for by the Council in consequence of its being stated, and indeed shown, that the technical education of this country was so much inferior to that in

other European states, as to threaten seriously the industrial interests of Great Britain.

The duty of promoting and encouraging a better theoretical education for engineering students had been urged upon them; but before coming to any determination on the question, they thought it desirable to obtain full information upon the status of the engineer and upon the facilities given, and the means adopted, in all countries for his education and training.

The Council observe in the publication alluded to, that it is essential to "distinguish clearly between the two kinds of education which it is generally deemed desirable an engineer should receive.

"In the first place, he should be acquainted with such physical sciences as bear on his profession, and should be familiar with the rules and operations necessary to apply their principles in practice. The imparting of this knowledge may be termed the theoretical education of the engineer.

"Secondly, he must be acquainted by actual experience with the nature of practical works and with the operations and processes necessary for their design and construction. The obtaining of this knowledge is his practical education."

The late Mr. Vignoles, F.R.S., in his address as President, gave a very complete description of engineering in France. There, and in nearly all other European nations following the example of France, the engineering works of the countries are almost wholly in the hands of the Governments. Few are considered engineers or find employment except those who have been educated in the special schools provided for them; and though the technical or theoretical knowledge thus acquired is, it must be admitted, superior as a rule to that generally imparted in this country, students lack that practical knowledge which has hitherto been the main source of the success of the English engineer, who owes little or nothing to Government patronage, and whose employment depends on individual merit, the works being undertaken by private enterprise.

The Council, perhaps properly, drew few general conclusions from the information they obtained. They felt that they could not become a scholastic institution. They contented themselves with giving a description of the system and course of study pursued in each country, and added some valuable suggestions, for the improvement of theoretical knowledge in our own, from Sir John Rennie, Mr. Conybeare, Mr. Heppel, Mr. Callcott Reilly, the Society of Arts, Professor Fleeming Jenkin, Mr. Scott Russell, and Professor Leone Levi.

I may be permitted to quote from this volume the following description of our own system:—

"The theoretical knowledge which may be desired is obtained either by private reading or by attendance at the scientific classes established at various educational institutions, some of which have made special provision for studies of this kind.

"The practical education in England is perhaps the most perfect possible, if the opportunities obtained during the pupilage are ample and the pupil properly avails himself of them; for nothing can give a student so thorough and useful a knowledge of practical works as being actually engaged for a length of time upon them in a really working capacity; in addition to which the habits of business and the familiarity with all subsidiary arrangements acquired in this way, have a beneficial influence on the student's future career. This thorough proficiency in practical matters tends largely to compensate for—in some cases to outweigh—the deficiency in theoretical attainments; and it is undoubtedly this, influenced in some degree by the natural self-reliance and practical common sense inherent in the English character, which has given such a high standing to the profession in this country."

I must quote, too, on this point, the opinion of M. Flachat, Honorary President of the Société des Ingénieurs Civils de France:—

"In my opinion," says M. Flachat, "free industry forms the most useful engineers. This is the state of things in England. Government education, on the other hand, makes them more learned (*savans*). This is the case with our École des Mines, recruited from the École Polytechnique. Our École des Ponts et Chaussées has not been rich in *savans*, because the functions of the engineers coming from that school have long been, and still are very limited, and all emulation has been extinguished in them.

"I believe our system is much too centralized to suit England."

Still there can be little doubt, on a review of the whole question, that our young engineers are not always prepared by preliminary education as well as they might be, for their subsequent acquisition of practical knowledge. It is not because there are not institutions in this country where such knowledge can be obtained, but rather from a general laxity in the views of parents and guardians upon technical education. Special qualifications, and some of a very high order, are required to ensure success in our profession, and many young men enter it as pupils without these qualifications.

The mere enumeration of the public schools in which special instruction is given bearing on the profession of engineering, will

suffice to show that our deficiency in this country is not so great as has been supposed. These are:

King's College, London.
University College, London.
The Royal School of Mines, London.
The Royal School of Naval Architecture, London.
The University of Edinburgh.
The University of Glasgow.
Trinity College, Dublin.
The Royal College of Science, Dublin.
Queen's College, Cork.
Owen's College, Manchester.
The College at Durham.

Besides which may be mentioned:

The Royal Agricultural College, Cirencester.
The Whitworth Scholarships.
The Examination for the Engineering Service for India;

to say nothing of private establishments, or of the Royal Indian Engineering College at Cooper's Hill, which has been established since the publication of the information collected by the Council.

Some of these, as their names denote, are for instruction in special branches, but at many the scientific education is as comprehensive and complete as can be desired.

It would far exceed the limits of this address were I to go into a description of the course of study pursued in each; and I can do little more than commend the volume from which I have been quoting to the attention of all our Members and Associates, and to those who are interested in the prosperity of our future engineers. At most of the establishments named, the course of education extends over three years and is very complete. For instance, at King's College it consists of mathematics, natural philosophy in its various branches, including practical and experimental physics, the arts of construction in connection with civil engineering and architecture, manufacturing art and machinery, land surveying and levelling, drawing, chemistry, geology, and mineralogy, and photography; but, as explained by the authorities, the course of study "forms only an appropriate introduction to that kind of instruction which can only be obtained within the walls of the manufactory, or by actually taking part in the labours of the surveyor, the engineer, or the architect."

Most of these establishments which are not devoted to special

subjects, profess the education they give to be merely preliminary to the practical knowledge which can only be acquired by actual work; but at Trinity College, Dublin, and at Queen's College, Cork, young gentlemen are supposed to be thoroughly educated both in theory and practice, and to be fitted at once to act as engineers. I think this is a mistake, and has a mischievous effect upon the young men themselves, in inducing them to think they are masters of a profession of which they know but one half.

On the whole I am disposed to agree with Mr. Fleeming Jenkin, who, in a most sensible and comprehensive letter on engineering education, gives it as his opinion "that there is no reason for abandoning our system of apprenticeship or pupilage, to substitute for it the foreign plan of large special colleges, even if we could hope to form colleges of equal merit with those formed abroad; but this conclusion, instead of leading us to sit down wrapped comfortably in a veil of blinding self-conceit, ought rather to urge us to work with the greater vigour at removing the acknowledged defects of the British plan. We have not to construct the whole edifice anew, we have only to put on the cornice-stone. Our defect is the want of a good knowledge of the theories affecting our practice."

Since the publication of the volume to which I have been alluding, the Royal Indian Engineering College, at Cooper's Hill, has been established. This college was founded in 1871, under the orders of the Secretary of State for India in Council, in view to the education of civil engineers for the service of Government in the Indian Public Works Department. This branch of the public service is divided into four parts, namely, buildings and roads, irrigation works, railways, and accounts.

The whole strength of the department in 1840 was 113; in 1850, 183; in 1863, 545; in 1868, 747; and in 1874, nearly 1,200.

The course of special education extends over three years; and if the students succeed in passing the final test of qualification, they will be appointed to the Indian Public Works Department as assistant engineers.

A part of the third year has to be passed by the student under a civil or mechanical engineer. This, I presume, is for the purpose of his acquiring that practical knowledge on which so much of the success of the engineer depends; but as the actual execution of works in India is conducted by the executive and assistant engineers, I cannot think that many are qualified, by the information they acquire in a part of one year only, for the work which is expected from them.

The College has, no doubt, been established for the purpose of supplying a want which was felt; and the order of study has been fixed by able men, after mature deliberation. As a theoretical education, it is very complete, as will be seen from the obligatory subjects of study :—

Mathematics, pure and applied, with the mechanics of engineering.
Theory and practice of construction.
Elementary principles of architectural design.
Surveying.
Mechanical drawing and descriptive geometry.
Chemistry, physics, and geology.
Hindustani, and history and geography of India.
Accounts.

The optional subjects are :—

Higher Mathematics, in extension of the obligatory course.
Natural science, ditto.
Architecture, ditto.
Freehand Drawing.
Photography.

Two and one third, or two and a half years, for acquiring a competent knowledge of the above subjects, are surely short enough; and half a year, or two terms of the last year, are, in my opinion, a great deal too short for the acquisition of the practical knowledge which is necessary to the complete education of an engineer. I cannot, therefore, help expressing myself upon this Institution, as I have upon Trinity College, Dublin, and Queen's College, Cork, that the idea, which is evidently entertained, that a young gentleman will be thoroughly educated both in theory and practice, and fitted at once to act as an engineer, is a mistake, and has a mischievous effect in inducing him to think that he is master of a profession of which he has but a partial knowledge.

I am informed that a longer period than a part of a year is now given for acquiring practical knowledge, and it may be that the office of assistant engineer is a subordinate one, and affords opportunity of learning much of what may be considered deficient.

There is another public institution for education in practical engineering to which I should allude, viz., one recently established by the Crystal Palace Company.

"The leading object" of this school, as stated by the pro-

moters, "is to prepare students by systematic practical instruction, for professional articles, so that on entering an engineer's office or works, the pupil may at once be useful to his principal, and enabled to take advantage of the opportunities of learning open to him, because he has mastered the elementary details of his profession."

This seems to be a laudable arrangement, and, if successful and well supported, may be expected to be attended with beneficial results. The course is one year for preparation for mechanical engineering, and another year for civil engineering; but, as it only professes to be preparatory to the practical training to be subsequently obtained, it is free from the objections I have urged against Trinity College, Dublin, the Queen's College, Cork, and, to some extent, to the college at Cooper's Hill. The education, however, proposed to be given, is less complete and scientific than that at King's College, and other kindred establishments. A recent address at the Crystal Palace to the School of Practical Engineering, by Sir Arthur Cotton, on the material improvement of India, is well worth perusing.

Our members will have noticed that the Minutes of Proceedings have greatly increased in bulk of late years. This is owing to the summary of the Papers and proceedings of foreign societies, and of works executed in foreign countries. These are most valuable contributions to our knowledge and information, for the labour of collecting which we are mainly indebted to our very competent and indefatigable Secretary, Mr. Forrest.

I will now briefly refer to some of the principal engineering works which have either been completed or been under construction during the last two years.

Railways I need scarcely refer to. Many extensions have been made, but there is nothing particularly new which requires notice, except Mr. Bouch's great bridge across the river Tay at Dundee. This bridge, in many respects the largest railway bridge ever constructed, crosses the river Tay just above Dundee, and is known as the Tay bridge. It is a remarkable instance of bold commercial enterprise and engineering skill. It is 2¼ miles in length. It comprises eighty-five arches of 65, 145, and 245 feet span, and crosses the navigable portion of the river with a clear headway for vessels of 88 feet above high-water mark. The Chairman and Directors of the North British Railway Company, which is mainly interested in the construction of the bridge, passed over it in September last in a train drawn by a locomotive, and it may therefore be considered as completed at that

time, although it has not yet been opened to public traffic. Mr. Bouch, M. Inst. C.E., the engineer, promises a Paper on the subject.

In the supply of towns with water, many works have been constructed or completed during the last two years. Perhaps the most important is the final completion of the Longdendale branch of the Manchester waterworks after having been nearly thirty years in hand. The construction of these works has been attended with very great difficulty, owing to the dislocated and unsatisfactory character of the ground in the valley of Longdendale, in which five great reservoirs have been created, the embankments being of the respective heights above the river, of 60, 70, 80, 100, and 90 feet, forming a chain of lakes of about 7 miles in length, and containing in this valley alone about 635,000,000 cubic feet of water. In one case the puddle trench had to be sunk 160 feet below the level of the top bank, principally through rock, and was refilled for a depth of 110 feet with concrete, clay puddle being considered unable to bear the pressure. The quantity of water which the Corporation of Manchester may collect and supply from this district, is about 24,000,000 of gallons per day. The population now dependent on the Corporation for its supply of water is nearly eight hundred thousand.

Amongst docks and works of that description which have been completed or opened, or which have been under construction during the last two years, must be mentioned the Amsterdam canal, a dock at Avonmouth near Bristol, a dock at Fleetwood, the Stobcross Dock, now the Queen's Dock at Glasgow, the extension of the Victoria Docks and quay wall on the Thames, extension of the dock works at Liverpool and Birkenhead, and the breakwater at Madras.

The Amsterdam canal, one of the greatest works of the day, of which our Past-President, Sir John Hawkshaw, is Engineer in Chief, was opened in the course of last year. Its general features were so fully described by my predecessor, Mr. Harrison, that it is not necessary for me to do more than to refer to the completion of the undertaking, and to express the hope, which Mr. Harrison also indulged, that we may have a descriptive account of the work, abounding as it does, in points of interest and novelty of construction. A very full account of this canal and its many interesting details, has been published by the United States Government, being a Report by Major-General J. G. Barnard in 1872, and a short sketch is given in Mr. D. Stevenson's work in 1872, on the principle and practice of Canal and River Engineering. The

works were so far completed that on the 11th November, 1876, they were opened by the King in person for vessels drawing 17 feet of water. The ultimate depth is intended to be 21 or 22 feet, and the extra depth will be chiefly acquired by dredging.

The dock at Avonmouth is styled the Bristol Port and Channel Dock. The works consist of an entrance lock from the Bristol Channel 454 feet in length and 70 feet in width, and a dock 1,400 feet by 500 feet (about 16 acres in area). They have been constructed for the purpose of avoiding the narrow, tortuous river, leading from Avonmouth to Bristol, and in the expectation of affording such additional facilities to the port of Bristol as materially to increase the commerce. The high tides in the Severn and the Avon give the dock special advantages in admitting vessels of great depth of water, and it is said that all vessels afloat, except the Great Eastern, can enter and leave the dock. The depth of water over the sill of the lock, at equinoctial spring tides, is 42 feet, 38 feet at ordinary spring tides, and 26 feet at ordinary neap tides. The depth of water to be constantly maintained in the dock will not be less than 26 feet. The engineer is Mr. Brunlees, V. P. Inst. C.E., and the dock is placed in communication with all the inland railways by means of branches to the Great Western and Midland railways. The dock was opened on the 24th of February, 1877.

The Fleetwood Dock, of which the engineer is Sir John Hawkshaw, was opened in October last. It is 15 acres in extent, with a timber basin of 14 acres, and has been constructed to meet the growing wants of the port. The entrance lock is 200 feet long, 50 feet wide, and has a depth of water of 23·3 feet on the sill. The lock gates are of malleable iron.

The Queen's Dock, at Stobcross, near Glasgow, was so named by the gracious permission of Her Majesty, and was opened on the 18th of September last. It is a work of much interest, in consequence of the peculiar method by which the quay walls have been constructed, having for the most part been founded on concrete cylinders sunk in sand. This method of building was adopted by the trustees of the Clyde navigation, on the recommendation of myself and Mr. Deas, M. Inst. C.E., the Resident Engineer, and was first applied to the formation of the Plantation quay, on the opposite side of the river. The principle there adopted was described by Mr. Milroy, Assoc. Inst. C.E., in a Paper presented to the Institution in the year 1869, in describing the foundations of a railway bridge across the Clyde, and a general description of the dock works, as they were then intended, was given to the In-

stitution by Mr. Deas in the year 1873. Considerable progress has been made since that time, and the dock was partially opened, as before stated, on the 18th of September last. The entrance to the dock is 100 feet in width, across which a swing bridge, resting on triple concrete cylinders, has been erected by Sir William Armstrong and Co., and is shut and opened by hydraulic power, little more than a minute being occupied in each operation. By the system of construction adopted, no cofferdams are required, and as the quay walls are completed, and the ground excavated in front, so the dock may be occupied. When finished, there will be added to the already considerable ship accommodation on the Clyde, about $27\frac{1}{2}$ acres of quay space, and $33\frac{1}{2}$ acres of water space, 20 feet deep at low water. The tide rises from 7 to 9 feet.

Great additions have been made to the docks at Liverpool and Birkenhead, and the history of these works is so instructive that I cannot refrain from giving a short account of them, for the materials for which I am indebted to our Member of Council Mr. George Fosbery Lyster, M. Inst. C.E., the present able Engineer of the Mersey Dock and Harbour Board.

The new works, covering a large area of land reclaimed for the most part from the estuary of the Mersey, have been in progress during the past three years, and will probably occupy a total period of ten years before they are completed.

The power to construct the first dock in Liverpool was given by the Dock Act of 1709. Subsequently it was known as the Old Dock, and the level of its sill was adopted, and has been used ever since as the established datum of the port. It was a very humble beginning, not more than $3\frac{1}{2}$ acres in extent, but it is worthy of observation, perhaps, from the fact that it is one of the first recorded instances of the application of gates to a dock for the retention of water within it at all times at a nearly uniform level. To Mr. Thomas Steers the honour is due as Engineer, not only of this early work, but also as being one of the first to introduce dock gates to complete what is commonly called a wet dock.[1]

During the first hundred years, from the opening of the Old Dock, not much progress was made in works of that class at Liverpool. In 1816, the total wet dock area was only 34 acres. In 1825, shortly after the late Mr. Jesse Hartley's appointment as Dock Surveyor, it was 47 acres. By 1846, it had increased to

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[1] I have been informed that an Act was obtained in 1699 for the construction of a wet dock with gates at the Commercial Docks in the Thames, which would probably be completed about 1701.

108 acres, and in 1861, to 220 acres. Since that date, the additions to dock area, chiefly at Birkenhead, have been large and continuous. The Birkenhead Docks, originally projected by the late Mr. Rendel in 1844, but which up to 1858, when they were incorporated with the estate of the Mersey Docks and Harbour Board, had made but a feeble advancement, were now rapidly developed. From a wet dock area of about 7 acres, they were, by 1869, increased to 147 acres, and by subsequent additions up to the present time, exhibit a total of 160 acres, with a length of quayage of 9 miles.

Meanwhile, and subsequently, dock development on the Liverpool side of the Mersey had been almost suspended, 31 acres only having been added in the eleven years ending with 1872. As soon, however, as dock accommodation had been provided for the wants of Birkenhead, attention was once more directed to the demands of commerce in Liverpool.

As an indication of the growth of the shipping trade in the port, it may be stated that its tonnage, which for the year 1800 was 450,060 tons, and in 1817 had increased to only 653,425 tons, amounted in 1837 to 1,958,894 tons; in 1857, to 4,645,362 tons; and now, by the latest return for the twelve months ending 1st July, 1877, to a total of 7,000,726 tons.

The new works in course of construction at the northern and southern extremities of the dock estate, comprise, at the north, a a half tide dock of 18 acres, having two lock entrances, with an open basin direct from the Mersey, a great dock, with three branch docks leading out of it, of an aggregate area of 43 acres, and specially intended for the use of the large ocean-going steamship trade; an 18-acre dock for the accommodation of the coal trade; a repairing dock of 3 acres, and two graving docks. The new docks at the south will include special provision for the local carrying, import, and other trades of 32 acres. The total additions, north and south, will amount to 114 acres of wet dock area, with nearly 6 miles of quayage.

The design and execution of these works are entrusted to Mr. George Fosbery Lyster, who since 1861 has had the entire charge and management of the dock estate, in the capacity of Engineer to the Board.

On the completion of these great works, the area of the wet docks in Liverpool will amount to 365 acres, with 24 miles of quayage, which, with the Birkenhead Docks already quoted, will give a total wet dock area of 525 acres, and a lineal quayage of 33 miles.

The Madras harbour, as now in progress from the designs of Mr. W. Parkes, M. Inst. C.E., consists of breakwater piers run out to sea and returned towards each other, leaving an entrance of 150 yards in width, and enclosing about 140 acres of sheltered space, being, for the most part, from 4 to 7 fathoms in depth. The piers are formed, where more than 22 feet below low water, of rubble stone, dropped from steam hopper barges. From this level to 3½ feet above high water, they are built of concrete blocks, each 27 tons in weight, regularly placed by means of a Titan crane, in the manner described by Mr. Parkes, which was adopted by him in the formation of the Manora breakwater in the harbour of Kurrachee, of which an account is given in vol. 43 of our Minutes of Proceedings.

The weight of such blocks, and the manner in which they are put together, must have reference to local circumstances, and the power of the sea. These blocks are much heavier than those which form the outer breakwater of the harbour of Marseilles, and I believe of Cherbourg, but they are very much less than the monolith, which was moved at Wick. With reference to this, Mr. David Stevenson writes to me as follows:—"You will find all that is on record regarding the removal of the 1,400-ton block at Wick in the discussion on the Manora breakwater. It was replaced by a 2,600-ton block; and you will observe that I did speak even hopefully of the success of that larger block, for I said: 'Whether or not the billows, known locally as the wild "rollers" of Wick Bay, would leave this mass of masonry undisturbed, remained to be seen.' And now it has been seen, after remaining undisturbed for three years, the storm of the first week of January last carried it bodily away, moving it within the line of the breakwater where it now lies in two pieces."

In telegraph engineering much progress has been made during the last two years. A striking novelty has lately been produced in the telephones of Mr. Bell and Mr. Edison, instruments by which the human voice with all its modulations can be transmitted to great distances.

The "telephone" may be regarded as an extension of the powers of the "logograph," an instrument for recording the human voice, which was described by our Vice-President, Mr. W. H. Barlow, in a Paper read before the Royal Society three years ago.

The telephones of Mr. Bell and Mr. Edison differ in their con-

struction. One may be said to be a mechanical and the other a chemical arrangement, but both are indebted to the electric telegraph for the transmission of the human voice. Some difficulties have been experienced in bringing them to perfection, but their use is extremely recent, and the difficulties to be overcome are, I believe, small, compared to those already conquered by telegraph engineers. The telephone has been applied with success to the mines at St. Austell, in Cornwall, in giving instructions down the shafts; and in America it has been employed during the construction of a large bridge, by establishing communication between the superintendent's offices and the piers in course of construction. Probably a valuable application would be to enable a diver in his dress to communicate with the shore, and the telephone has already been put to use in this way.

One of Mr. Bell's instruments was sent to the Exhibition at Philadelphia last year, where it attracted much attention. Sir William Thomson gave the following report of it:—

"Mr. Alexander Graham Bell exhibits apparatus by which he has achieved a result of transcendent scientific interest—the transmission of spoken words by electric currents through a telegraph wire. To obtain this result, Mr. Bell perceived that he must produce a variation of strength of current in the telegraph wire as nearly as may be in exact proportion to the velocity of a particle of air moved by the sound, and he invented a method of doing so —a piece of iron attached to a membrane, and thus moved to and fro in the neighbourhood of an electro-magnet—which has proved perfectly successful. The battery and wire of this electro-magnet are in circuit with the telegraph wire and the wire of another electro-magnet at the receiving station. This second electro-magnet has a solid bar of iron for core, which is connected at one end by a thick disc of iron to an iron tube surrounding the coil and bar. The free circular end of the tube constitutes one pole of the electro-magnet, and the adjacent free end of the bar core the other. A thin circular iron disc held pressed against the end of the tube by the electric-magnetic attraction and free to vibrate through a very small space without touching the central pole, constitutes the sounder by which the electric effect is reconverted into sound. With my ear pressed against this disc I heard it speak distinctly several sentences. . . . . I need scarcely say I was astonished and delighted; so were others, including some judges of our group, who witnessed the experiments and verified with their own ears the electric transmission of speech. This, perhaps the greatest marvel hitherto achieved by the electric telegraph, has been

obtained by appliances of quite a homespun and rudimentary character. With somewhat more advanced plans and more powerful apparatus, we may confidently expect that Mr. Bell will give us the means of making voice and spoken words audible through the electric wire, to an ear hundreds of miles distant."

Since this high testimonial was given by Sir William Thomson, great improvements have been made in Mr. Bell's telephone; and I must refer my hearers to an interesting lecture by him, given at the meeting of the Society of Arts on the 30th of November, 1877.

Within the last two years, the quadruplex system of telegraphy, imported into this country from America, has also come into use. By this system, two messages are sent in each direction by the same wire at the same time. This is probably the latest invention, and if perfected, so as to be practically available, it will very greatly increase the speed and lessen the cost of telegraphic communication.

Great speed of transmission has been effected by the careful manner in which the oceanic cable of the Direct United States Cable Company has been prepared and laid. The average of such speed has been about eighteen words per minute, but by improved instruments it has been found possible to record twenty-eight words per minute in ordinary Morse signals, through an unbroken length of 2,500 nautical miles of cable.

But during the past year electricity has put forward new claims other than those relating to means of communication. The Electric light is not likely to compete successfully with the convenience in domestic arrangements of the present system of gas lighting, but for the illumination of large spaces, the electric light has been found to be very useful and effective.

In this branch of the subject our distinguished Member of Council, Dr. Siemens, in conjunction with his brother, has brought his inventive faculty to bear; and from the investigations and experiments of Dr. Tyndall and Mr. Douglass, the Trinity House authorities have determined to apply an invention of his to the electric lights for the Lizard Point lighthouses.

Another important application of electricity has been pointed out by Dr. Siemens, in his recent inaugural address as President of the Iron and Steel Institute, namely, the transmission of motive power. There seems to be much promise in this suggestion, and it is worthy the careful consideration of engineers; but time will not allow me to enter into particulars. I can only hope that Dr. Siemens, or some one in connection with him, may be induced to

bring this, as well as other branches of electricity before the Institution at some of the meetings of the present session.

The mention of the application of the electric light to the Lizard Point lighthouses naturally invites attention to the subject of lighthouses, a subject which it is rather remarkable has never yet been treated or alluded to in any presidential address, although several valuable Papers exist in our Minutes of Proceedings. No branch of engineering is attended with more difficulty or requires more careful consideration, and none is more intimately connected with the preservation of life and property in this maritime country. The Institution will join me in the regret which must be felt at the announcement which was made by Mr. Douglass, M. Inst. C.E., the Engineer to the Trinity House, at the meeting of the British Association at Plymouth in September last, that the Edystone lighthouse, the glory of the father of civil engineering, John Smeaton, has become unsafe and must be pulled down, and another be substituted for it.

The present lighthouse was completed in 1759, since which time it has withstood all the raging storms of the Atlantic, storms which have not unfrequently thrown the water over the top of the lantern, nearly 80 feet above the level of the sea.

Mr. Douglass reports that the tower is at present in a good state, but unfortunately the portion of the hard gneiss reef on which it is founded has been seriously undermined and weakened by the sea. It has therefore been determined to erect another, for which a good site has been found at about 120 feet from the present one. Such has been the improvement in the illumination of lighthouses since the Edystone was first erected, that the light now exhibited there is one hundred and nine times the intensity of the original light. This will be greatly increased in the lighthouse about to be erected.

The Edystone lighthouse may be considered as the model from which all subsequent houses of the same character and exposed to similar seas have been erected, and I must join Mr. Douglass in the wish that if it be taken down, as it will be, after the erection of the new one, the nation will consider it as worthy of a site on English soil as Cleopatra's Needle.

Many lighthouses have been constructed since Smeaton built the Edystone, and of some of them interesting accounts will be found in our proceedings. Keeping to what has been recently done, we have an account of the Dhu Heartach lighthouse, by Mr. D. A. Stevenson, in the early part of 1876, erected by the Commissioners of Northern Lights after the design of Messrs. D.

and T. Stevenson, MM. Inst. C.E. This lighthouse is erected on the principal island of the Dhu Heartach group, occupying an important position with regard to the Irish Channel, to the Frith of Clyde, and to the navigation of the Minch. Its erection was attended with many difficulties, such indeed as are common to this difficult and dangerous class of work, and six seasons were required to erect it. It stands on a rock 35 feet above high-water spring-tides, with deep water on all sides, and is similar in construction to the Edystone and the Skerryvore lighthouses, the latter having been the subject of a treatise by its able and lamented Author, Mr. Alan Stevenson. The Dhu Heartach tower is 107½ feet in height above its foundation, and is a parabolic frustum surmounted by a plain cavetto, abacus, and parapet. The maximum diameter of the base is 36 feet, and the minimum at the top 16 feet. It was begun in 1867 and completed in 1873 at a cost of £76,084 1*s.* 7*d.*

I have been favoured by Mr. Douglass with the perusal of a Report of a tour of inspection of European Lighthouse establishments made in 1873, by Major G. H. Elliot,[1] of the United States, which contains a full and complete account of the Lighthouses of Great Britain, Ireland, and France, and to this Report, printed at the Government Office, Washington, U.S., I would refer all who are specially interested in this branch of engineering.

Turning now to a subject on which my professional avocations have given me the opportunity of acquiring a good deal of minute information, I propose to enter shortly upon the subject of rainfall and the quantity of water which flows off the ground, available for the use of man if properly utilised, or destructive when uncontrolled and permitted to cause floods or torrents.

I propose to confine my observations to this country only.

It is remarkable that previous to the present century we knew little or nothing of the question to which I am now referring. Probably the earliest investigation into the quantity of rain which fell and that which flowed off the ground, is that contained in an essay by the late Dr. Dalton, which was addressed to the Literary and Philosophical Society of Manchester in 1799. Dr. Dalton's essay was entitled, "Experiments and Observations to determine whether the quantity of rain and dew is equal to the quantity of water carried off by rivers and raised by evaporation, with an inquiry into the origin of springs." He examined the various opinions, which at that time existed upon the origin of springs,

[1] A copy of this report is in the library of the Inst. C.E.

combating the supposition that they were derived from some hidden subterraneous source, concluding that they must be attributed solely to the rain, their variations depending upon the seasons, and upon the quantity of rain which falls.

At this time Dr. Dalton determined that the average precipitation of rain and dew throughout the kingdom was 36 inches, allowing 31 inches for rain and 5 inches for dew. The highest returns of rain before him were from Kendal and Keswick, both under 60 inches per annum. Observations since then, some of the most important conducted by Dr. Miller, of Whitehaven, have proved that the rain in many parts of the country far exceeds this quantity. In the mountainous district of Westmoreland and Cumberland, Dr. Miller ascertained that the rain amounts in one locality to nearly 200 inches per annum. Indeed the rainfall in the British Islands varies to a much greater extent than Dr. Dalton had any idea of. He found, by experiments, in Manchester, that the rain on the ground was greater than the rain on the top of St. Mary's Church, many feet higher in a direct line upwards.

The late Professor Phillips found the same result from experiments at York, on the ground, on the top of St. Mary's Abbey, and on the top of York Minster, and from these experiments, it was, by many, concluded that the rain on elevated ground would be less than on low ground.

In Dr. Dalton's time, however, mountain gauges were not known. The observations upon the fall of rain had been principally taken near the residences of the observers, and they would, of course, be in cultivated or residential districts, all comparatively low in elevation. The variation is very great. On the east coast of England and Scotland the average rainfall will probably not exceed 20 inches per annum, while, on the south and west coasts, it will average 35 or 40 inches, or double that on the east. In the mountainous districts, which form the backbone of England, the rain will amount to 40, 50, and 60 inches per annum. In the mountains of Wales, and in those which surround the Cumberland and Westmoreland Lakes, the general average of the rain will be from 60 to 80 inches, and in some parts of the lake district it amounts to upwards of 150 inches in average years.

Some of the earliest gauges for the purpose of ascertaining the fall of rain on high lands, were put down by myself in the Mourne Mountains, in Ireland in the year 1836, and across the Pennine range of hills, dividing Lancashire and Cheshire from Yorkshire and Derbyshire, in 1839, and which were carefully observed for many years.

From that time observations have been general, and a vast amount of important facts has consequently been accumulated. Amongst the most interesting, and probably the most important of these observations, are those, which about the same time were established by Mr. J. F. Miller, of Whitehaven, afterwards Dr. Miller, to the cost of which many members of this Institution and others contributed.

These observations were made principally for the purpose of ascertaining the fall of rain upon the high mountains of that district, and to ascertain the increase or diminution which took place in consequence of elevation.

In his Annual Report for 1847, Dr. Miller makes many valuable and interesting observations, which want of time alone prevents my quoting.

From these observations he drew the conclusion that, "as a general rule, in mountainous districts, the rain increases from the valley upwards, to an altitude of about 2,000 feet, and that above this altitude the quantity rapidly decreases." He then gives the returns for twenty-one months as follows:—

	Elevation above Sea.	Inches.
The Valley, Head of Borrowdale. . .	160	170·55
Stye Head	1,290	185·74
Seatoller	1,334 (?)	180·28
Sparkling Tarn	1,920	207·91
Great Gabel	2,925	136·98
Sca Fell	3,166	128·15

Dr. Miller also observes as to the value of the experiments, that " they have already shown us that at least 60 inches more rain is deposited in England than we were previously aware of; that 150 inches sometimes descend in the Lake districts in a year—more than falls in most part of the Tropics, with which we are acquainted, and sufficient to drown, standing, two of the tallest men in Great Britain one on the top of the other. They have further informed us that 6½ perpendicular inches of water is sometimes precipitated from the atmosphere in twenty-four hours, and 10 inches in forty-eight hours; a quantity which would be thought large enough for any two consecutive months in most parts of England.

"A little consideration will greatly lessen our surprise at the enormous quantity of water deposited in the hilly districts of Cumberland and Westmoreland, and at the consequent unequal distribution of the rain in the climate of Great Britain. To those

unacquainted with these localities, it may be briefly stated that the Lake district valleys radiate from a series of mountains of slate and primitive rock, having the Gabel, 2,928 feet in height, as a nucleus or central point; and in the immediate vicinity of which are Sca Fell and Pillar, of the respective elevations of 3,166 and 2,893 feet, and Great End, Bow Fell, and Glaramara, not much inferior in altitude. These mountains are distant only about 13 or 15 miles, in a direct line, from the Irish Channel, and as no hills intervene, they are consequently fully exposed to our wet and prevailing winds, which are the south-west. The warm south-westerly current arrives at the coast loaded with moisture, obtained in its transit across the Atlantic. Now, our experiments justify us in concluding that this current has its maximum density at about 2,000 feet above the sea level; hence it will travel onward until it is obstructed by land of sufficient elevation to precipitate its vapour; and retaining a portion of the velocity of the lower parallel of latitude whence it was originally set in motion, it rapidly traverses the short space of level country, and with little diminution of its weight or volume; but on reaching the mountains, it meets with a temperature many degrees lower than the point at which it can continue in a state of vapour; sudden condensation consequently ensues in the form of vast torrents of rain, which in some instances must descend in almost a continuous sheet, as when 9 or 10 inches are precipitated in forty-eight hours. When we reflect that a warm moist current, perhaps only 3° or 4° above the point of saturation, in coming in contact with the mountain ridge, probably meets with a stratum of air 10° or 15° lower than its own inherent temperature, we shall cease to marvel that such quantities as 4, 5, or even 6 inches of water should be deposited in these localities in the course of a few hours. The mountains are in fact huge natural condensers, destined to force from the atmosphere the mighty volumes of water requisite for the supply of our lakes and rivers."

I have quoted largely from Dr. Miller, because I cannot express in better language the conclusions at which he arrived, and which I believe to be in accordance with all the experience which has subsequently been gained.

It will be observed that he concludes that the maximum density of the rain cloud is at about 2,000 feet above the sea level; and by turning to the instances which I have quoted, of the fall of rain, it will be found that the rain gradually increases up to Sparkling Tarn, which is 1,900 feet above the sea, where in twenty-one months it amounted to 208 inches. At Great Gabel,

2,925 feet above the sea, it had diminished to 137 inches; and at Sca Fell, 3,166 feet, it had further diminished to 128 inches. The Valley in this table, which is only 160 feet above the sea, is immediately below Stye Head, on the easterly side of that pass. Stye Head itself, 1,290 feet, is a pass in a range of mountains which generally exceed 2,000 feet in elevation, running up to 3,000 feet. It is situated at the narrow end of a funnel opening over Wast Water to the south-west. Up this funnel, from the open Irish sea, the rain cloud is driven until it is impeded in its further progress by the wall of mountains which rises to 3,000 feet in elevation, nearly the only depression in which is the pass of Stye Head. Through this pass the clouds are driven, and in the valley on the other side, protected from the westerly winds, the clouds may be said to rest, and there to discharge their contents.

It will be seen from this, that while the general conclusion may be drawn that the rain will increase upon elevated land up to about 2,000 feet, and will decrease at elevations exceeding that height, local circumstances exercise an important influence upon the quantity of rain which really reaches the earth.

Another conclusion which may be drawn from these observations, is, that in a range of mountains which exceeds 2,000 feet in height, the greatest deposition of rain may be expected on that side of the mountain upon which the rain clouds impinge. That in ranges of mountains or hills which do not rise so high as 2,000 feet, the rain clouds may be expected to be driven over the summits, and to discharge their watery contents on that side of the mountains which is protected from the winds, and consequently on the opposite side to that upon which the rain cloud first impinges.

Another conclusion which may be drawn, is, that in a succession of ridges and valleys which are opposed to the passage of rain clouds, but where the ranges of mountains, although contributing largely to precipitation, are not of a height sufficient to stop the further progress of the rain cloud, but will permit its being driven over the first summit into the first trough or valley, and so on over the second and third summits with their intervening troughs, the rain may be expected to be the greatest in the first trough in which the rain clouds rest. Extensive observations have proved these conclusions, which may be reasonably drawn from Dr. Miller's observations, to be absolutely correct.

Thus a ridge exceeding 2,000 feet high would have comparatively little rain on the east side, assuming that the westerly winds are those which bring the greatest amount of rain. Such a ridge

would stop nearly all the rain clouds from the west, and the water would be precipitated on the westerly slopes. In the north of England, it is well known that the westerly wind is a dry wind on the coast of Northumberland, while it is a wet wind on the west coast, and that a wet wind on the coast of Northumberland is a dry wind in the western portion of the country, although the hills are not so high as to absolutely intercept the rain.

Where there is a range of mountains, the summits of which measure upwards of 3,000 feet, with depressions in the ridge, the largest amount of rain will be in the valleys to the east of those depressions. Where the rain clouds can be forced into a narrow valley and pressed over a depression like Stye Head into a valley like Borrowdale, then on the easterly side there will be by far the largest fall of rain.

The district of the Liverpool waterworks affords a good illustration of these facts. The water is obtained from the Rivington Hills, the first high ground to the west of the flat land which extends some distance inwards from Liverpool. These hills do not exceed 1,600 or 1,700 feet in height, and the rainfall at Rivington is about 50 inches. The Bolton waterworks are in the first trough over these hills, the trough running pretty nearly south and north. The westerly winds impinge upon the westerly slopes of the mountains, which form the drainage area of the Liverpool waterworks, and on the average of ten years the rain there is about 48½ inches. The rain at Belmont in the Bolton waterworks, to the eastward of the Rivington Hills, and in the first trough over the summit of the most westerly hills, is 53 inches per annum. The next trough is the valley from which the Blackburn waterworks are supplied, and there the rain is 42 inches. On the first slope of the westerly side of the hill there are about 48½ inches, then about 53 inches in the first trough, and 42 inches in the second; when you get away over the mountains and right down into the east, the rainfall is only about 30 inches.

The Manchester waterworks, in Longdendale, are formed in a valley running east and west in a mountain range, the Pennine chain of hills, commonly called the Backbone of England. The rain at Manchester in 1859 was 38 inches in round numbers. Going eastward at Denton, 300 feet above the sea, the rain was 34 inches. At Newton, farther eastward, it was 35 inches; a little farther 33 inches. All these places are upon the plain or tolerably level ground. Then we come to the foot of the hills where the rain is 46½ inches. Higher up, at the head of the valley 1,000 feet

above the sea on the west side, it is 53⅓ inches and 57·64 inches. On the east side just over the summit it is 58½ inches. At Penistone, a few miles to the east of the hills, the rain is 39 inches, and at Sheffield 25 inches; showing that the rain is larger on the west than it is on the east, increasing as the ground ascends, and rapidly diminishing as it falls to the east.

On the line of the Rochdale canal, which also crosses the Backbone of England, in the same way in the year 1848 at Rochdale, which is at the west foot of the hills, the rain was $39\frac{7}{10}$ inches. At Whiteholme, on the top of the hills, the rain was $66\frac{7}{10}$ inches. At Blackstone Edge Toll-bar 67½ inches, and on the east side $66\frac{6}{10}$ inches; but these three last places are nearly on the summit of hills not more than 1,200 feet high. Descending eastward to Sowerby Bridge, which is at the easterly foot, the rain is 32·27 inches, and at Halifax it is less than that.

The same results are observed in the mountain ranges which surround the Scotch lakes. Loch Lomond and Loch Katrine will be known to most and the high mountain district about them. To the west of Loch Lomond there are very high mountains in Argyleshire, forming barriers to the rain clouds which are brought from the Atlantic. Every successive trough or valley to the east has a diminished quantity of rain, and so has also almost every successive range of mountains going from west to east.

Beginning at the west, there is first the great valley of Loch Long, then that of Loch Lomond, succeeded by Loch Ard, Loch Katrine and Loch Vennachar, and, lastly, by Loch Lubnaig. The drainage ground of the Glasgow waterworks is in the valley of Lock Katrine and Loch Vennachar. It is hemmed in by mountains varying from 2,000 to 3,000 feet in height. This valley is shut out from the south-west by hills immediately adjoining Loch Katrine, varying from about 2,393 feet to 2,514 feet above the sea, with depressions of not more than 500 feet above that level.

The well-known mountain of Ben Lomond, which lies betwixt the Loch Ard and Loch Lomond valleys, is 3,192 feet high. I had for some years a rain gauge on the flanks of this mountain, and in 1854 there were 109 inches, at an elevation of 1,800 feet. On the hills betwixt Loch Ard and Loch Katrine, which is the next successive range of hills to the east, the rain was 67 inches. On the hills near Glen Finlas, further to the east, at an elevation of 1,800 feet, the rain was 62 inches. In 1857, the rain on the first ridge was 85½ inches, on the second, $74\frac{2}{10}$ inches, and on the third ridge, $48\frac{3}{10}$ inches. In 1859, two years afterwards, it was 92, 85⅓, and 48

inches respectively. In 1875, 80·1, 68·7, and 56·8 inches, and so for every year.

These observations show the importance of bearing in mind that it does not do simply to calculate upon increased elevation giving increased quantity of rain, but that the whole question is affected by the geographical disposition of mountains and valleys.

Again, the heads of all valleys in mountainous districts give larger quantities of rain than the mouths of the valleys. Thus at Loch Vennachar, at the mouth of the great valley in which that loch and Loch Katrine lie, the rain in 1872 was 78 inches at an elevation of 275 feet above the sea; while at Glen Gyle, 380 feet above the sea, at the head of Loch Katrine, the rain was $127\frac{8}{10}$ inches, and in the same year, on the flanks of Ben Lomond, at 1,800 feet above the sea, it was $96\frac{1}{2}$ inches. In the year 1866 the rain at Loch Vennachar was 64 inches; at the head of Loch Katrine 101 inches; and on Ben Lomond, 100 inches.

These remarks will probably suffice to show how much the rain varies in the same district without reference to elevation, the variations depending upon the physical and geographical features of the country. Nothing, therefore, is more fallacious than to attempt to determine by any fixed ratio the amount of rain which will probably fall in any district, unless there be some corresponding district, similar in elevation, in proximity to the sea, in exposure to wind, and in other external circumstances with which to compare it. Only very extended observation and the application of the judgment acquired by experience will enable an engineer to form an accurate estimate of the probable rainfall of a district.

It is right to observe that the accuracy of some of the early observations recorded by myself was questioned, because the index-rod by which the depth was measured was allowed to remain for some time in the gauge. Those taken during the last thirty years are free from this objection.

Mr. Symons has for many years collected observations from all parts of the country; so that our knowlege on this subject is largely increased. His labours as a collector are beyond all praise.

We now come to the next important branch of this question, namely, the proportion of this very varying rainfall which will flow off from the surface of the country.

Here, geological conditions enter largely into the consideration. The quantity of water, or the proportion of rainfall which flows from the surface, depends upon a great variety of circumstances: upon the character of the rocks, upon their elevation and declivity,

and upon the manner in which they are clothed with vegetation, as well as upon the quantity of rain which falls upon the surface.

Thus the quantity of water which may be expected to flow from a flat country well clothed with vegetation will be very different from that which will pour in torrents down the steep declivities of uncovered mountains; and again, the water which will pass off from the surface of a limestone district, with its many caverns and perpendicular fissures, will vary considerably from that which will drain off in like manner from a district, similar perhaps in external features, but consisting of the dense rock of a primitive formation or the flat beds of the Coal Measures. Clay and sand, morass and cultivated ground, absorbent chalk, and more impervious material, all contribute to produce a varying result.

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The sands of the new red sandstone formation also absorb most of the water which falls upon them, as do also the local beds of

inches respectively. In 1875, 80·1, 68·7, and 56·8 inches, and so for every year.

These observations show the importance of bearing in mind that it does not do simply to calculate upon increased elevation giving increased quantity of rain, but that the whole question is affected by the geographical disposition of mountains and valleys.

Again, the heads of all valleys in mountainous districts give larger quantities of rain than the mouths of the valleys. Thus at Loch Vennachar, at the mouth of the great valley in which that loch and Loch Katrine lie, the rain in 1872 was 78 inches at an elevation of 275 feet above the sea; while at Glen Gyle, 380 feet above the sea, at the head of Loch Katrine, the rain was $127\frac{8}{10}$ inches, and in the same year, on the flanks of Ben Lomond, at 1,800 feet above the sea, it was $96\frac{1}{2}$ inches. In the year 1866 the rain at Loch Vennachar was 64 inches; at the head of Loch Katrine 101 inches; and on Ben Lomond, 100 inches.

These remarks will probably suffice to show how much the rain varies in the same district without reference to elevation, the variations depending upon the physical and geographical features of the country. Nothing, therefore, is more fallacious than to attempt to determine by any fixed ratio the amount of rain which will probably fall in any district, unless there be some corresponding district, similar in elevation, in proximity to the sea, in exposure to wind, and in other external circumstances with which to compare it. Only very extended observation and the application of the judgment acquired by experience will enable an engineer to form an accurate estimate of the probable rainfall of a district.

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We now come to the next important branch of this question, namely, the proportion of this very varying rainfall which will flow off from the surface of the country.

Here, geological conditions enter largely into the consideration. The quantity of water, or the proportion of rainfall which flows from the surface, depends upon a great variety of circumstances: upon the character of the rocks, upon their elevation and declivity,

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sand and gravel found interspersed amongst the clays of the diluvium.

From all these sources, produced by absorbent measures, large quantities of spring water may undoubtedly be procured, often continuing with little daily variation. Many single springs yield several hundred thousand gallons a day; some amount to upwards of 1,000,000, and there are a few which far exceed this quantity, forming at once rivers of considerable volume. Such are the source of the Aire at Malham Cove, in Yorkshire; the Syreford spring and seven wells, sources of the Thames, near Cheltenham; the Hoggs Mill river near Ewell in Surrey; the spring at Holywell in Wales, and many others.

Passing from these absorbent measures which are so eminently productive of springs, to those of older date and harder or closer texture, I am able to give, from extensive observation, some information upon the volume of spring water produced by the sandstone district of the lower coal measures, and the millstone grit formation immediately beneath. These two groups of rocks usually produce spring water of great excellence and softness, but owing to their general horizontal stratification, the frequent and great extent to which they are covered by drift clay, and the numerous beds of impervious shale with which the sandstones and flag rocks are interstratified; and also to the steep and hilly character of the surface which generally prevails where these formations are present, the bulk of the rain which falls flows off the ground in floods, and a comparatively small portion finds its way through cracks and fissures into the interior of the earth to be reproduced as springs. Hence it is seldom that springs are found here in great volume, but the quantity from equal areas varies considerably.

Generally, in the coal measures and millstone grit formations, and in the primitive geological formations, the quantity of spring water in the driest seasons will vary from about $\frac{1}{4}$ of a cubic foot per second per 1,000 acres to $\frac{3}{4}$ of a cubic foot per second per 1,000 acres; $\frac{1}{2}$ a foot per second per 1,000 acres would be an average quantity in a dry season.

Many careful observations upon this point have been taken. At Halifax, in 1868, which was a season of drought, the average quantity of water flowing down a river, which received the drainage of 2,325 acres, for the four months of May, June, July, and August, was 0·332 of a cubic foot per second per 1,000 acres. From another stream receiving the water from 9,322 acres, the average for the same four months was 0·452 cubic foot per second per 1,000 acres.

The river Teith in 1826, another season of drought, from 122,000 acres, averaged 0·6 cubic foot per 1,000 acres during a period of one hundred days, the minimum supply being 0·3. At the Manchester waterworks, from 18,000 acres in 1864, the average per 1,000 acres was 2·05 cubic feet for one hundred and forty days. In 1865, 1·647, and in 1868, from 0·511 to 0·776 cubic foot per second for seventy and one hundred and fifty days respectively. At Dublin in 1868, from 14,080 acres, it was 1·308 cubic foot for one hundred and forty-one days, and at Liverpool, in the same year, from 10,000 acres it was 0·398 cubic foot for one hundred and sixty-one days.

This branch of the subject is very important in relation to the working power of a stream—to the minimum quantity which it will yield for irrigation, for agricultural purposes, or for supplies to towns, or the addition which such supplies of spring water will make to the quantity to be obtained from storage reservoirs for any of the above purposes. It is also important in the consideration of the effect of long drought upon the beds of rivers and the mouths of harbours. . . . . .

The quantity of water, however, passed down in such seasons forms but a very small portion of that which is carried away by floods; for, while from the geological measures we have last been speaking of, the ordinary volume of the river will only be about half a cubic foot per second for every 1,000 acres in a dry season, the floods in the same river may, and will vary from 200 cubic feet per second from the same area, to 400 and 500 cubic feet per second, showing that the floods are from five hundred or six hundred to one thousand times greater than the mere quantity of water in dry seasons.

Lakes or reservoirs in the hills, and inundated or flooded lands in the low districts, check and diminish these quantities.

It is this quantity of water which it is most important to ascertain and to consider in all engineering operations. It is the flood waters which must fill the large storage reservoirs that are necessary for the supply of canals, for water power, and for the use of towns. It is the quantity of water brought down by floods which has to be provided for in spanning rivers by bridges, in the construction of river courses, or in enlarging or maintaining those which exist, and in carrying out measures for the drainage of lands; and their effect in "scour" upon the beds of the rivers themselves, and upon the mouths of harbours. These are important considerations in determining the scale and character of engineering works. Where the channel of a river is not large

enough to carry away the floods, the water overflows the banks or edges of the river and inundates the land; and if it be necessary to protect such land from the devastating effects of floods, it becomes an important problem to ascertain the volume of water to be provided for, and to be passed with safety, and the heights or distances of the banks, and the area of the channels for effecting this object. It is therefore of importance to ascertain how much of the rain which falls is lost to the rivers and springs by evaporation, or by being taken up by vegetation.

The first accurate observer on a large scale in this department appears to have been the late ingenious Mr. Thom, of Rothesay, the constructor of the Shaw's waterworks near Greenock.

The following is the result of information which he gave many years ago to this Institution on the rain which fell in 1826 and 1828, the former year being the driest year on record, and the latter, one in which there fell more than the average amount of rain:—

	Inches.
From the 1st April, 1826, to 1st April, 1827, the fall of rain in Bute was	45·4
Of which there found its way to the reservoir	23·9
Lost to the reservoir	21·5

In 1828, the rain at Greenock reservoir was 60 inches, of which there flowed to the reservoir 41 inches, showing a loss by evaporation, vegetation, absorption, &c., of 19 inches. Further observations by Mr. Thom led him to the conclusion that the loss bore a certain definite proportion to the rainfall; and the late Mr. Stirrat, of Paisley, also an accurate observer, viewed the question in the same light; their average results giving the loss at about $\frac{3}{10}$ or $\frac{4}{10}$ of the whole fall, when the annual amount was from 54 to 65 inches. This conclusion was no doubt correctly arrived at from the facts before them; but it is obvious from a little reflection that this mode of calculation is inapplicable to other districts, where a much larger or a much smaller quantity of rain might fall. For instance, the requirements of vegetation and the amount of evaporation are usually much less where a large quantity of rain falls, while at the same time the ground is generally less absorbent and the declivities greater; and it evidently follows that the loss by evaporation and vegetation must be less under such circumstances than in a rich level country where the rain is not nearly so great. By assuming a certain definite proportion of the whole rain, the reverse would appear to be the case. Take, by way of illustration, 100 inches in a sterile mountainous country, the loss at $\frac{3}{10}$ would be 30 inches;

and take 30 inches again as the rain in a fertile level country, the loss at $\frac{3}{10}$ would be but 9 inches—obviously inconsistent with the real facts of the case. The truth appears to be, that the loss within certain limits is a tolerably constant quantity, and that generally the greater the rain the less the deduction ought to be.

The observations of Mr. Thom and Mr. Stirrat give the annual loss at from 18 to 23 inches per annum, out of rainfalls of 54 inches and 65 inches respectively. Measurements and observations in 1852 in the Gorbals waterworks district, closely adjoining those in which these observations were made, and in which there is about the same amount of rain, show the loss to have been but 12 inches out of 60 inches.

Other observations, scattered over the country, show the loss to be ordinarily from 10 to 18 inches, and to a great extent to be irrespective of the rain which falls. In determining, therefore, the probable quantity of water which may be collected from any district, other than one of an absorbent character, it is necessary, first, to ascertain the fall of rain, and then—having due regard to the state of cultivation, to physical features and geological structure—to make such a deduction for the loss by evaporation and vegetation, as, in the absence of correct experiments, may under the circumstances appear to be just.

The year 1852 was a remarkable year, not only in its meteorological features, but as affording valuable information for the guidance of the hydraulic engineer. In that year there occurred probably, one of the longest droughts of which we have any correct record, and the heaviest falls of rain within short periods. The total annual fall was but an average, and reservoirs for a town's supply should have been able to collect nearly all the water which flowed off the ground during the periods of excessive wet, to have afforded a full daily supply throughout the whole duration of the drought. In the Manchester waterworks, the rain was just an average—about 50 inches per annum. Rather more than half the whole quantity fell in the two first and two last months of the year. The quantity of water which flowed from 18,900 acres between the 1st of January and the 9th of February exceeded 800,000,000 cubic feet. The rain in the same period, taking the average of what was indicated by the gauges, was 12 inches. The flow from the ground, accurately measured through reservoirs, equalled 12½ inches, the rain gauges evidently indicating less than the real fall. From the evening of the 4th of February to the morning of the 5th, the quantity of water received into the reservoirs was equal to a depth over the whole surface of the

ground of $2\frac{4}{10}$ inches. This excessive rain was followed by a drought of one hundred and ten days in duration, occasional wet days having occurred during this period, which would reduce the net duration of the drought to one hundred and five days.

In the year 1850, at the Whittle Dean waterworks, which supply Newcastle-upon-Tyne, the reservoirs went down constantly for two hundred and forty days, the whole available produce of the district being but $6\frac{1}{3}$ inches in the year out of $17\frac{3}{4}$ inches of rainfall. During the years 1873 and 1874, the drought at these works may be said to have lasted for five hundred and sixty days, viz., from the 19th April, 1873, to 1st November, 1874, or eighteen and a half months, during which period the rain at Hallington, about twenty miles inland from Newcastle, was only 38·87 inches, the average of eleven years being 46·47 inches. During this period of eighteen and a half months, the total flow from the ground was but $11\frac{1}{4}$ inches, being at the rate of $7\frac{1}{3}$ inches per annum. The loss per annum by absorption and evaporation was about 18 inches per annum, out of about $25\frac{1}{2}$ inches.

At Warrington, in the year 1854, there was no appreciable supply of water for two hundred and thirty days, the reservoirs and springs constantly decreasing during that period. The total produce of the year was but 8 inches out of 27 inches of rainfall.

In the Manchester waterworks, from nine years' observations, the quantity of water flowing off the ground was $39\frac{1}{2}$ inches out of $49\frac{1}{2}$, showing a loss of 10 inches. The rain gauges from which these results are obtained are placed in the valley of Longdendale, which show a less amount of rain than the average fall over the whole district. Gauges were kept on the tops of the hills for many years, but not during the nine years over which these observations extend. Comparing the hill gauges with those in the valley during the time both were kept, it is found that an addition of about 10 per cent. must be made to the fall of rain registered in the valley in order to ascertain the real amount falling over the whole district. This has accordingly been done, and the average rain of $49\frac{1}{2}$ inches is 10 per cent. more than the mean of the valley gaugings.

In conclusion, it may with proper pride be said by engineers, that there is no body of men to whom such large sums of money are intrusted, or on whose honesty and judgment their due expenditure so much depends. It is not to be expected that directors and employers can know much of the proper cost of engineering works, nor that they should be able to discriminate between the saving

effected by a man of knowledge and experience and the lavish or foolish outlay of a tyro in the profession.

The responsibility of the engineer is great. Arduous and difficult duties are often placed upon him. He has almost uncontrolled command of money. He is generally the arbitrator in all questions of dispute between the employer and the employed. His integrity, honesty, and independence should be above all suspicion. He should lean neither to the one side nor to the other, and his judgments should be so clearly those of knowledge and equity that they should be entitled to as much respect as those of a judge on the bench.

It may take a lifetime to earn such a character for ability, fairness, and integrity as will create entire confidence in all parties interested, but it should be the aim of every engineer to attain it; and I think I may confidently say that he will attain it if he deserves it.

January 22, 1878.

JOHN FREDERIC BATEMAN, F.R.SS. L. & E., President, in the Chair.

No. 1,545.—"Some Recent Improvements in Dynamo-electric Apparatus." By RICHARD WILLIAM HENRY PAGET HIGGS, LL.D., Assoc. Inst. C.E., and JOHN RICHARD BRITTLE, Assoc. Inst. C.E.[1]

THE growth of electrical invention has been so rapid, that its definition and nomenclature are to a great extent confined to its technologists. For this reason it may be desirable to indicate what is meant by a dynamo-electric machine, and advisable to review briefly the rise and progress of this branch of electricity. Compared with other branches of engineering science this is of very modern date. The principle of magneto-electricity was discovered by Faraday: to him is due the first statement of the fact, that when a bar of iron is surrounded by a coil or helix of wire, and a magnet is approached to or drawn from the bar, a current of electricity is induced in the coil. Further, he found that when one pole of the magnet was approached to the bar, the electrical current had a direction opposite to that electrical current produced when the magnet was receded from the bar: also that the opposite poles of the magnet had opposite actions, or, in other words, produced by the same movement currents of opposite directions. His researches proved that the soft iron and the magnet might change places, and that, generally, electric currents were produced in a coil placed in a magnetic field, either by changes of intensity of this magnetic field, or by the coil being made to cut through magnetic rays of different intensities.

The practical application of this important addition to electrical knowledge soon appeared in the first magneto-electric machine, constructed in 1833, by Pixii. In this machine a horse-shoe magnet was caused to revolve with its poles before those of a double electro-magnet. This machine had the mechanical disadvantage that the heavier part of it—the permanent magnet—was put in motion. First Saxton and then Clarke improved upon

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[1] The discussion upon this Paper occupied portions of three evenings, but an abstract of the whole is given consecutively.

this construction in machines of small dimensions, the magnets in which were fixed, and the coil caused to rotate.

The use of machines of large size driven at high speed appears to have been suggested by Professor Nollet, of Brussels. Machines of this kind, virtually on the principle of Clarke's machine, but of modified form, have been constructed by Holmes, of London, and the Compagnie l'Alliance, of Paris.

In 1854 Dr. Siemens, of Berlin, introduced an important improvement, now known as the Siemens armature. This consisted in the adoption of an electro-magnet of peculiar form. The iron core of this electro-magnet, or armature, as it is technically termed, is a cylinder deeply and widely grooved along the opposite sides, the groove being continued round the ends. The wire is wound in this groove. Instead of the poles being at the ends of the cylinder, as in the ordinary form of electro-magnets, they are constituted by the two cylindrical faces left by the grooving. This armature has several advantages. It can from its form be caused to revolve (parallel to the axis of the cylinder) at a high speed, and from its small size can be maintained in an intense magnetic field with the use of magnets of moderate size. As in Clarke's machine, the polarity of the armature is reversed at each half revolution, and for electro-metallurgical processes the alternating currents are reduced to a common direction by means of a commutator. Mr. Wilde introduced the principle of accumulation by successive action, by combining two of these cylindrical armature machines, one larger than the other, the larger machine being furnished with an electro-magnet instead of with permanent magnets. The two cylindrical armatures are caused to revolve, and the current produced is conveyed by the small machine through the electro-magnet coils of the larger machine, the latter acquiring a permanent magnetic force of great intensity. This principle of accumulation by successive action can be extended to a third armature, but a proportionately larger amount of energy must be expended in driving the machine.

All these machines may be classed as magneto-electric, that is to say, the current produced depends upon the action of magnets upon an electrical circuit. Magneto-electric machines are quite distinct from electro-magnetic machines, in which the electrical current is made to produce movement, being itself generated by a source foreign to the motor.

Magneto-electric machines are disadvantageous in use, because their effect does not increase with their dimensions, and machines for the production of powerful currents become cumbersome and

costly. The rapid rotation, and consequently rapid reversals of magnetism of the iron core, give rise to great heating of the working parts, and to the necessity of cooling these with water. In 1867, Dr. Siemens patented (No. 261) a machine to obviate these rapid reversals. The construction adopted was that of a circular or ring magnet, which was caused to rotate in a direction with its periphery, the ring passing through the centre of coils of wire.

The step from magneto-electric to dynamo-electric machines was due to Dr. Werner Siemens, Sir Charles Wheatstone, and Mr. S. Alfred Varley, who quite independently discovered and worked upon the same principle of accumulation by mutual action, the priority falling to Dr. Siemens by previous publication. In this construction of machine, induced currents are caused to circulate in the electro-magnet coils that produce them, and are in this way increased. By this mutual action currents are produced the limit of intensity of which is co-equal with the maximum limit of magnetic saturation. This principle of accumulation by mutual action is now employed in all machines where currents of great intensity are required. The last step that, combined with the preceding, has yielded to modern science the present intensely powerful machines is the disuse of the commutator, for changing alternate currents into currents of a common direction. This has been effected in the Siemens machine by a method of winding the wire on the armature, devised by Von Hefner Alteneck, and presently to be described. In the Gramme machine, which also gives currents of common direction, a principle is employed, described by Pacinotti in 1863, of whose apparatus the present Gramme machine is a modification. In the Gramme machine wire is coiled in circular rings transversely upon an iron ring, the ends of the coils of wire being brought to a commutator, where the current is collected. Currents are induced in the coils upon this ring by the action of powerful external electro-magnets, upon the principle of accumulation by mutual action. In point of construction the Gramme machine is inferior to the machine to be fully described in this Paper, from the fact that the whole of the wire coiled upon the ring is not subject to direct inductive influence, that portion of the wire which passes around each coil in the inside of the ring not being acted upon by the inducing electro-magnets. As in all electro-magnetic apparatus, wire coils not acted upon inductively tend to set up opposite self-induced currents, which weaken the main current. This arrangement, as well as offering a disadvantage of construction

by the expenditure of twice as much armature wire as is effective, is undoubtedly somewhat detrimental to the efficiency of the machine. The Siemens, as well as the Gramme machines, are single-acting, that is to say, only one armature is employed in each machine.

This necessarily imperfect sketch may perhaps serve to indicate the steps by which the present powerful dynamo-electric machines have resulted from the earlier studies of magneto-electricity.

Latest Construction of Siemens' Dynamo-electric Machine.

The principle of all dynamo- and magneto-electric machines is the same. Passage of a closed electrical circuit through a magnetic field generates a current in that circuit, the direction of the current depending upon the position of the magnetic poles and the direction of motion of the electrical conductor. In the latest form of the Siemens machine this conductor is of insulated copper wire, coiled in several lengths and convolutions upon a cylinder, shown in transverse section in Plate 1, Fig. 1, in longitudinal section in Fig. 2, and in plan by Fig. 3. Each convolution is parallel to the longitudinal axis of the cylinder, and the whole surface of the cylinder is covered with wire, laid on in six sections, as shown in Fig 1. Surrounding the wire cylinder for about two-thirds of its surface are curved iron bars, the space between these curved bars and the wire cylinder being as small as is consistent with the free rotation of the cylinder. The curved bars are themselves the prolongations of the cores of large flat electro-magnets; the coils of these electro-magnets and the wire of the cylinder (from brush to brush) form a continuous electrical circuit. Upon revolution of the wire cylinder (which is supported upon a longitudinal axis in proper bearings, the axis carrying a pulley) a current is generated in it, and this current, initially weak, is directed into the coils of the electro-magnets, magnetising the cores, which induce a still stronger current in the wire cylinder. This mutual action continues until the magnetic limit of the iron is attained. At every revolution of the wire cylinder, the maximum magnetic power acting upon each convolution is attained when the convolution passes through the middle of both magnetic fields, and this power falls to zero when the convolution is perpendicular to that position. Each convolution is therefore subject to a neutral position, and by Lenz's law a convolution starting from that position on the one side of the axis towards the north pole of the electro-magnet would be subject to a direct induced current, and

that portion of the convolution on the opposite side of the axis will be traversed by a current of opposite direction, as regards a given point, but of the same direction as regards circuit.

Each of these six sections of wire coiled upon the cylinder consists of two separate coils, leaving twenty-four ends; two of these ends are brought to each of the segments of a circular commutator having twelve divisions, as shown in Fig. 4. But all the coils are connected to the several segments of the commutator, as shown in Fig. 5, in such a manner that the whole six double sections form a continuous circuit, but not one continuous helix.

In order that the segments may be properly presented to the collecting brushes, the connections are arranged as in Fig. 5, in which, however, only eight segments are shown for simplification. The ends of the same length of wire are numbered 1 and 1′, 2 and 2′, &c., and the signs plus and minus show the electrical polarity of each wire (regarded for itself) according to the relative momentary position. The electric currents are collected upon two wire brushes tangential to the segments of the commutator, as in Fig. 4, and these brushes form, through the electro-magnets, the two electrodes of the machine, and to the electro-magnet ends are connected the conducting wires leading to the lamp or other system where the current is to be utilised.

The dimensions, weights, number of revolutions made by the cylinder, light equivalent in normal candles, and HP. required for driving, are for three sizes of machines as under:—

Dimensions in inches.			Weight in lbs.	Revolutions of Cylinder.	Candles Light.	HP.
Length.	Width.	Height.				
25	21	8·8	298	1,100	1,000	1½ to 2
29	26	9·5	419	850	4,000	3 to 3½
44	28·3	12·6	1,279	480	14,800	9 to 10

The Electric Lamp.

Many forms of lamp have been proposed. The principles involved in their construction may be classed under two heads:— 1. Lamps in which the light is maintained between two carbon points; 2. Those in which a continuous carbon rod is heated by the current to incandescence. The lamp about to be described is one of the former class. This class might be again subdivided to

include, under different kinds, lamps that are automatic in their action and lamps depending upon clockwork for a part of their functions.

The lamp it is preferred to use with the Siemens machine is shown in Plate 2, Fig. 6 being a back view partly in section, and Fig. 7 being a vertical section at right angles to Fig. 6.

Supposing the carbons to be inserted in their holders and properly clamped, they will, if their points are separated, be brought together again by the gravitation of the top carbon and its holder. The top carbon clamp is attached to a vertical tube, and this carries at its lower end a straight rack. This rack is inclosed in another tube, fixed to the top of the lamp casing, in which the tube carrying the carbon clamp slides, electrical contact being maintained between the two tubes by copper springs of a suitable form. The descent of the top carbon actuates, by means of the rack, a large pinion, the spindle (the second from the top in the diagram) of which carries a small pinion gearing into a second rack placed upon the opposite side of the spindle and attached to the lower carbon holder, which slides in a similar manner to the other carbon holder. The superior weight of the top carbon and holder in conjunction with the multiplying ratio of the two pinions produces a continual tendency of the carbons to approach each other. The large and small pinions are connected to each other and to the spindle that carries them by an arrangement of friction discs. The object of this mode of construction is to permit the two racks to be moved equally and simultaneously up or down for the purpose, when required, of focussing the light. This focussing movement is effected by the bevelled gearing, shown in the upper part of the casing, actuated by a milled head which can be pressed into position when required. On the spindle carrying the large and small pinions and the friction discs is placed a toothed wheel connected with the spindle by a pawl and ratchet. This wheel is the first of a train of wheels and pinions driving a regulating fly in the usual way. The pawl and ratchet are provided to permit the rapid distancing of the carbon holders when it becomes necessary to introduce new carbons. The spindle of the fly also carries a small finely-toothed ratchet wheel. This ratchet wheel is actuated by a spring pawl carried at the end of a lever, which lever is the continuation of the armature of an electro-magnet, in such a manner that when the armature is attracted by the electro-magnet, the spring pawl engages in the teeth of the ratchet wheel and causes the wheels in gearing therewith to act upon the racks of the carbon holders to draw them apart.

The construction of the lamp has now been sufficiently explained to enable its action to be understood. The current passes from the conductor to the top carbon holder, thence through the carbons to the bottom carbon holder, and so to the coils of the electro-magnet situated in the bottom of the lamp. From the coils of the electro-magnet the circuit is completed to the other conductor. Upon the current first passing through the circuit, the armature of the electro-magnet is attracted and the abutment from the armature lever caused to short-circuit the coils of the electro-magnet, releasing the armature. When the armature is released the short-circuit is removed from the coils of the electro-magnet and the cycle of movement is repeated. In this way oscillatory motion is given to the armature lever, which by the spring pawl actuates the ratchet wheel, the train of wheelwork, and the racks of the carbon holders, forcing the carbons apart until the distance between the carbon points sufficiently weakens the current so that it no longer attracts the armature of the electro-magnet. Thus by the combined action of gravitation of the top carbon in drawing the carbons together, and of the current to separate the carbons when these approach too closely, a working distance is automatically maintained between the points.

This lamp has been specially constructed for lighthouse illumination, its working parts being so arranged that every adjustment can be made from the back of the lamp. The carbon holders, clamps, and all parts of the lamp which it is necessary to introduce into the holophote are constructed to pass through a narrow slit or opening in the lenses.

Lamps of construction similar to this are being supplied to the Trinity House for the new system of electric lighting to be established at the Lizard Lighthouse.

The Self-acting Shunt.

A point requiring notice in the action of dynamo-electric machines is that, when the outer circuit of the machine is closed, that is, when the machine is producing a current, the resistance offered to the rotation of the wire cylinder is very great; when the exterior circuit is interrupted this resistance ceases. Therefore, if a motor, such as a steam engine, is employed to drive a dynamo machine, so that the work done by the dynamo machine is the only load upon the engine, it follows that the sudden interruption of the outer circuit, by removal of the load from the engine, might lead to injury either of the engine or of the machine

from increased velocity of rotation. It is only in one application of the machine, namely, to that of electric lighting, that such an interruption of the outer circuit is likely to occur, and to meet the difficulty, a self-acting shunt has been devised; in practice, however, with the lamp previously described, its use has not been a necessity.

This apparatus is connected to both leading wires between the machine and the lamp. The details of the shunt are shown in Fig. 8, Plate 1. It contains a small electro-magnet with its armature (which has a back contact) and a coil of wire of resistance about equal to that of the electric arc. As long as the light is burning the electric current circulates in the coils of the electro-magnet, and the armature being strongly attracted interrupts the back contact. The resistance coil is, therefore, not in electrical circuit. Should the light be extinguished the current in the coils of the electro-magnet ceases, and the armature is withdrawn by the spring to the contact. This offers to the electric current a path of resistance equal to that of the lamp. The current of the dynamo-electric machine is, therefore, subject to scarcely any variation, and the driving motor has no cause to increase its speed. When, in consequence of the automatic action of the lamp, the carbon points again touch, the current passes once more through the coils of the electro-magnet and the armature is attracted, thus removing the shunt from the circuit.

Application to Lighting purposes.

The chief purpose for which dynamo-electric machines have up to the present time been employed is for the production of the electric light. But the Authors would point out that the applications are not confined to this, but may be extended to the transmission of power and to the production of chemical effect.

In the application to lighting purposes, the improvements in construction of the present dynamo machines are very obvious. The magneto-electric machines first employed in lighthouse illumination bear, as pointed out by Professor Tyndall in his "Report to the Elder Brethren of the Trinity House," a cost of 10 to 1 as compared with the latest dynamo machine, while the cubic spaces occupied are as 25 to 1, and the weights of the old and new machines as 13·7 to 1, the total light-power produced for the condensed beam of light being as about 1 to 5. Thus with a cost 10 times, with a weight 14 times, and a volume 25 times that of

the latest construction, the old machine produced one-fifth of the light, with an expenditure of practically the same driving power. Fig. 11, giving the results of experiments made by Captain Abney, R.E., at Fort Monkton, in July 1875, will show how the modern construction of machines has resulted in improved lighting power. The comparison is between the magneto-electric machine of Wilde, a dynamo-electric machine of Gramme, and a large machine of Siemens. The unbroken line shows optical values, and the dotted line actinic values of the light. The diagram shows for the Siemens machine, a rapid increase of light, with regard to power expended, compared with the other machines; but as this machine was intended to produce only great lighting power (14,000 candles), the initial point of the curve is high.

Table A shows the optical values for power expended.

TABLE A.—RESULTS of EXPERIMENTS made with ELECTRIC LIGHT APPARATUS at FORT MONKTON, July 1875.

Tabular Statement of the Value of the Lights.

Name of Machine.	Value at 18′ Distance. Optical.	Value at 18′ Distance. Actinic.	HP.	No. of Revolutions of Armature.	Remarks.
Wilde's 32 magnets	62	58	9·6	507	$\frac{3}{4}$-inch carbons.
" 32 "	56	36	11·1	497	$\frac{1}{2}$-inch "
" 24 "	32	24	7·1	688	
" 10 "	8	5	5·7	1,012	
Gramme's large .	100	95	6·3	473	
" "	61	61	9·9	473	Top carbon on edge of bottom.
" "	58	56	6·0	432	
" "	48	41	2·8	323	
" "	12	6	1·4	259	
Gramme's small .	5	4	2·4	1,006	
Siemens . . .	124	114	7·4	411	Top carbon on edge of bottom.
" . . .	92	67	5·9	377	
" . . .	87	42	5·8	365	
Sun Light . . .	1,000	..	..	..	

A later and more instructive series of experiments is however contained in the Trinity House Report on the "Comparative Trials of Electric Lights at the South Foreland," from August 1876 to July 1877, from which the following statement is taken (see next page).

STATEMENT SHOWING the DIMENSIONS, WEIGHT, HP. ABSORBED, and LIGHT PRODUCED. "SOUTH FORELAND" EXPERIMENTS.

Names of Machines.	Dimensions.			Weights.	HP. Absorbed.	Revolutions per Minute.	Light Produced in Standard Candles.		Light Produced per HP. in Standard Candles.		Size of Carbons.	Order of Merit.
	Length.	Breadth.	Width.				Condensed Beam.	Diffused Beam.	Condensed Beam.	Diffused Beam.		
	Ft. Ins.	Ft. Ins.	Ft. Ins.	T. cwt. q. lbs.							In. In.	
Holmes . . .	4 11	4 4	5 2	2 11 1 7	3·2	400	1,523	1,523	476	476	$\frac{3}{8} \times \frac{3}{8}$	6
Alliance . .	4 4	4 6	4 10	1 16 1 21	3·6	400	1,953	1,953	543	543	$\frac{3}{8} \times \frac{3}{8}$	5
Gramme (No. 1) . .	2 7	2 7	4 1	1 5 2 0	5·3	420	6,663	4,016	1,257	758	$\frac{1}{2} \times \frac{1}{2}$	4
Gramme (No. 2) . .	2 7	2 7	4 1	1 5 2 0	5·74	420	6,663	4,016	1,257	758	$\frac{1}{2} \times \frac{1}{2}$	4
Siemens (Large) .	3 9	2 5	1 2	0 11 2 18	9·8	480	14,818	8,932	1,512	911	$\frac{11}{16} \times \frac{11}{16}$	3
Siemens (Small, No. 58) . .	2 2	2 5	0 10	0 3 3 0	3·5	850	5,539	3,339	1,582	954	$\frac{1}{2} \times \frac{1}{2}$	2
Siemens (Small, No. 68) . .	2 2	2 5	0 10	0 3 3 0	3·3	850	6,864	4,138	2,080	1,254	$\frac{1}{2} \times \frac{1}{2}$	1

These experiments were made by the following comparisons:—

1. Holmes Magneto-electric	with	Siemens No. 1 Machine.	
2. " "	"	"	No. 2 "
3. " "	"	Gramme Machine.	
4. " "	"	Two Gramme Machines.	
5. Gramme "	"	Siemens No. 1 Machine.	
6. Siemens No. 1	"	Gramme.	
7. Gramme	"	Siemens No. 2.	
8. Siemens No. 2	"	Gramme.	

The Report states that, "For the photometric measurements of the light, the flame of the Trinity House 6-wick lamp, when consuming colza oil, was adopted as the standard. This lamp was placed at a distance of 100 feet from the electric lamp, and the measurements were taken by a Bunsen photometer. The 6-wick lamp was maintained, as nearly as practicable, at its intensity of 722 standard candles, and this intensity was checked from time to time by candle measurements taken with a separate Sugg photometer."

"The adoption of the powerful flame of the 6-wick lamp[1] for the measurements of the intensity of the electric light has been found to materially facilitate, and add to, the certainty of the operation. The white colour of the flame of this lamp, compared with that of the English standard candle, or French standard Carcel lamp, is greatly in its favour for the purpose."

THE BEST USE OF TWO MACHINES TO PRODUCE ONE LIGHT.

From experiments made with the Gramme machine it has been found that, by coupling two machines in what is electrically known as parallel circuit, light effects are produced exceeding the sum of the light effects separately given by each machine. An experiment made with two Siemens machines gave for one machine a light intensity represented by 4,446, and for another machine 6,563, the sum of which is 11,009; while the machines when coupled parallel gave an intensity of 13,179, being an increase of 19·7 per cent. The following table gives the comparative results of coupling two machines of similar construction, the weight and dimensions being

[1] The Authors of this Paper would suggest, where such a lamp is not to be obtained, that comparisons should be made between the lights of a standard candle and a paraffin lamp and an oxy-hydrogen light. They have found that the latter light can be steadily maintained for photometric purposes, and from its tint is easily comparable with the electric light; and by the use of an intermediate paraffin lamp, preferably with a Silber burner, the oxy-hydrogen light can be conveniently referred to a standard candle.

of course double those previously given for these machines, as well as the cost:—

STATEMENT SHOWING the HP. ABSORBED and LIGHT PRODUCED by MACHINES COUPLED in PARALLEL CIRCUIT.

Names of Machines.	HP. absorbed.	Revolutions per Minute.	Light produced in Standard Candles.		Light produced per HP. in Standard Candles.		Size of Carbons.
			Condensed Beam.	Diffused Beam.	Condensed Beam.	Diffused Beam.	In. In.
2 Holmes . . .	6·5	400	2,811	2,811	432	432	$\frac{1}{2} \times \frac{1}{2}$
2 Gramme . .	10·5	420	11,396	6,869	1,085	654	$\frac{11}{16} \times \frac{11}{16}$
2 Siemens small (Nos. 58 & 68) .	6·6	850	14,134	8,520	2,141	1,291	$\frac{11}{16} \times \frac{11}{16}$

INFLUENCE OF CIRCUIT RESISTANCE UPON LIGHT EFFECT.

An important factor in the light efficiency of a given machine is the resistance of the circuit leading to the lamps. Theoretically the maximum light effect should be produced when the resistance of the exterior circuit is a minimum, because upon the exterior circuit there is no inductive action, the true or real exterior circuit of a dynamo machine being the electro-magnets exercising inductive action. In practice, however, there is a maximum of external resistance which produces least tendency to sparks at the collecting brushes, and greatest current in the exterior circuit. This practical maximum seems to be obtained when the resistance of the exterior circuit is equal to that of the machine. But experiments based upon measurement of resulting light effect are very unsatisfactory, for the reason, in some slight degree, that the methods of optical measurements are untrustworthy, but mainly because no two pairs of carbons are equivalent in their action. There is, however, not the least doubt that, were care devoted to the obtaining of a homogeneous set of carbons with a well-regulated motor, a series of instructive experiments might be made. In the trials at the South Foreland, there were laid down for the service between the High Lighthouse and the engine-room, a distance of 694 feet, three insulated conducting cables. Two of these were small cables adapted for a single Holmes machine, and consisting each of seven copper wires, No. 14, B.W.G. It was necessary for the experiments to couple these two small cables together, giving a length of 1,286 feet, and a resistance of about 0·32 Siemens unit,

With the Holmes machine, which has the highest internal resistance, the loss was 16·1 per cent.; with the Gramme machine, which has a much smaller resistance than the Holmes machine, but still greater than the Siemens, the loss is 31·3 per cent.; with the Siemens machine, having the lowest resistance, the loss was 43·4 per cent. A larger cable being supplied, the loss of light with the Siemens machine was reduced to 23 to 24 per cent. of the whole light; while two machines coupled gave a loss of 35 per cent., the coupling of course reducing the resistance of the machines one-half. The employment of this larger cable with the Alliance machine gave a loss of 69·1 per cent of the whole light, and with the Holmes machine the loss of light was raised to 66·1 per cent., and with two Holmes machines coupled the loss was raised to 76·5 per cent. These trials serve to indicate that to obtain a maximum of light the resistance of the conducting wires should be properly proportioned to that of the machine.

Wear, Tear, and Renewals.

In the use of dynamo- or magneto-electric machines, the chances of stoppages have been quoted as a serious disadvantage, but the chances have been so reduced as to bring them to the level of those arising with machines generally. The Trinity House Report states that, "the No. 68 Siemens machine worked well from the 7th March to the 7th April without any necessity for a stoppage. On the 11th March the commutator plates and brushes were adjusted; on the 19th the brushes were renewed; on the 28th the commutator plates and brushes were again adjusted; and on the 6th April the commutator plates and brushes were renewed."

The duration of the light, owing to required renewal of carbons, is limited to a certain number of hours, which depends on the size of the carbons and of the machine employed. In the lamp illustrated in Plate 2, the lower carbon is 8 inches long and the upper carbon 16 inches long, and the clamps are arranged to take a round or square carbon from 0·354 to 0·827 inch thick, but the duration of the carbons will depend upon the use of a single machine, or coupled machines, and the sizes of the machines. About eight to ten hours is the longest time of duration of the carbons.

Electric Lighting as compared with Gas Lighting.

Much excitement has recently been evinced as to the probable competition between gas and electricity as sources of light-power. Although under certain circumstances these two agents un-

doubtedly come into competition, they have two separate fields. Hitherto gas has been generally employed for lighting spaces of both large and small dimensions, because a better source of light for large spaces has not been procurable with economy. But for lighting large spaces that are not subdivided by opaque objects or screens, it is a want of economy to employ gas. If, in fact, a gasworks were to be constructed simply for lighting large spaces, as does occur in some extensive works, the disbursement necessary to establish even a small gasworks would, compared with that necessary to establish the electric light, be a considerable multiple of the latter. Assuming light-power proportional to HP. expended (although it increases at a greater rate), 100 HP. would give 150,000 candles' light; if this be distributed from three points, the cost of each lamp per hour would not be more than 7*s.* 6*d.*, or £1 2*s.* 6*d.* per hour for the three, each light-centre giving an illumination which would enable small print to be read at a distance of a ¼ mile from the light. A burner giving the light of twenty candles consumes 6 cubic feet of gas per hour, which may be manufactured at a cost of 2*s.* per 1,000 cubic feet. This gives 7,500 burners' light only, and 45,000 cubic feet of gas at a cost of £4 10*s.* per hour, a ratio of 4 to 1 in favour of electric lighting. Electric lighting, where adopted, has been found to be generally more economical than gas lighting, but the economical ratios differ greatly, and are dependent chiefly upon the price of gas and the motor power employed. For large spaces the cost of electric lighting is about one-fourth or even one-fifth of that of gas lighting, when steam has been used as power and wear and tear are reckoned. With a gas engine as motor, the ratio has only been as 1 to 3,[1] the greatest economy having been with a turbine as motor.[2] At M. Dieu's workshops at Davours, the cost per hour for gas is 2*s.* 0·632*d.* against 1*s.* 7·2*d.* for electric lighting.[3] M. Ducommun[4] finds, taking into account wear and tear and interest, that gas costs 2·25 times more than the electric light, which ratio increases to 7·15 when wear and tear and interest are left out of consideration. At Messrs. Siemens Brothers' Telegraph Works, the cable shops are imperfectly lighted with one hundred and twenty gas-burners. Each of these burners consumes 6 cubic feet per hour, at a cost of 3*s.* 9*d.* per 1,000 cubic feet. The cost of

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[1] Fontaine's "Éclairage électrique."
[2] Fontaine's "Revue industrielle," vol. vii., p. 1.
[3] "Journal l'Éclairage au Gaz," vol. xxv., p. 132.
[4] "Bulletin de la Société industrielle de Mulhouse," 1876, p. 175.

fixing gas pipes, including cost of pipes, burners, cocks, &c., for the one hundred and twenty burners is £60. Taking interest at 15 per cent. to include wear and tear and renewals, there results for 1,000 hours' consumption per annum,

	£.	s.	d.
Interest	9	0	0
Cost of gas consumed	135	0	0
	144	0	0

At the utmost the one hundred and twenty burners cannot give more than 2,400 candles' light, and actually but a small percentage of this is reached. Further, when steam or other vapours, or fog, arise the gas-jets are obscured. The space being subdivided, it is necessary to employ three machines. These three machines, with lamps, conducting wires, mounting, &c., cost £250.

	£.	s.	d.
Interest 15 per cent. upon £250	37	10	0
Carbons, coals, attendance, oil, &c., for 1,000 hours .	35	4	0
	72	14	0

Thus the economy is as 2 to 1 in favour of electric lighting. But there is the further advantage that the lighting is perfect, and that steam or vapours or fog do not cause inconvenience. If, however, the ratio of light-intensities were adopted as the ratio of efficiency, the advantage would be considerably higher (20 to 1) in favour of electric lighting. It may be laid down as proved by experience, that for lighting large spaces, not too much subdivided, the advantage is greatly in favour of the electric light; but that where numerous light-centres of small intensity are required, or where the space is much subdivided, the advantage is in favour of gas. This advantage will cease when a practical method of subdividing the electric light has been obtained. In places where opaque objects or screens occur that only throw shadow but are not of sufficient size to completely block out the light from the space they inclose, reflectors can be utilised to overcome the difficulty of shadows. When the electric light is capable of minute subdivision it will undoubtedly compete with gas on terms of the highest advantage, since the cost of establishing a gas-works will be many times in excess of that necessary to supply the electric light to a district.

The objection, that the glare of the electric light is trying to the eyes of workpeople has been overcome by inclosing the light in an opaque reflector, the rays being projected on to a screen, or

on the ceiling or roof of the room or building, whence they are diffused, giving to the space lighted the appearance of illumination by daylight.

TRANSMISSION OF POWER TO A DISTANCE.

The means at present employed for the transmission of power to a distance are well known. In adding to the list it may be well to point out that between the use of electricity, when obtained from a voltaic battery and conveyed to an electro-magnetic motor by conducting wires, and the employment of dynamo machines, there is just the difference that results in obtaining the electric light by a Grove or a Bunsen battery, and in taking the light from the current produced by the dynamo machine. In the one case an expensive chemical action is converted into force; in the other the force produced by a steam or other economical motor is transmitted. With the electro-magnetic motor the system is generative; with the dynamo machine the current acts merely as a means of transmitting power produced by an independent motor. In point of fact this independent motor may be a natural source of power, such as the fall of water, the utilisation of the product of oil wells with prime-movers situated at these wells, &c.

The limit set by distance to the transmission of power, by means at present adopted, has been comparatively narrow. Hydraulic power has been the most adaptable, with, however, several important disadvantages. Although electricity as a means of transmission is also limited by the distance to be traversed, the limit is in this case much more extensible, and under favourable instances practically disappears. The limit is dependent upon the quantity of electricity that can be conveyed by the conductor, since mechanical efficiency depends upon the magnetic energy, and this is far more closely related to the quantity than to the intensity of the electric current. To convey a large quantity of electricity requires a conducting wire of a proportionate section, and this for extreme distances introduces the element of cost. Electrical conductor resistance is known to be inversely proportional to the conductor section—that is, to the square of the diameter—and directly proportional to the length. So that with a conductor of appreciable resistance, which gives the greatest efficiency with a given system of machines, if the distance between the motor and moved machines be increased to *n* times the original distance, the section of the conductor must be increased *n* times to maintain the same quantity of current and the same ratio of efficiency in the system. Now as the cost of material for the

conductor wires may be taken as proportional to the weight, and the weight is proportional to the section, it follows that the cost of a conducting system giving a certain efficiency being known, the cost of a conducting system of increased length may be calculated with ease. The rate has been considered by some who have estimated the cost of these systems of transmission to follow the law of telegraphic transmission on electric cables, but the idea is erroneous. In electric telegraph cables the transmission constant depends upon two factors, the resistance of the conductor and the electrostatic capacity of its insulating sheathing. But with transmission of electric power only one factor appears, namely, that of conductor resistance. So that instead of the efficiency of transmission decreasing with a ratio following that of the squares of the lengths of the conducting systems, the decrease is proportional merely to the length. As to cost, when that of a conducting system for a known distance is c, if this distance be increased n times, then to maintain the same ratio of efficiency between driving and driven systems, and the original electrical resistance, the section of the conductor must also be increased n times, whence the cost of the greater length is $c\,n^2$. In other words, keeping the driving and driven systems constant, the cost of a conductor system may be assumed to be proportional to the square of the distance. But this supposes that there is no increase in power or alteration in the transmitting machines, whereas this alteration would certainly be made where the distances were greatly increased, and the cost of the conductor system would thus be reduced to a new standard.

For the transmission of power, say from a steam or water motor initially, the following system is adopted:—First a strap or belt from the motor is carried to the pulley of the driving dynamo-electric machine which generates the current. By leading-wires of the required length the electrical current generated in the first machine is conveyed to the terminals of a second and precisely similar machine. Thus the first machine generates the current, which is utilised in imparting motion to the second machine. It remains to review the probable efficiency of such a system. This subject has been treated in its mathematical relations by M. Mascart in the "Journal de Physique,"[1] an abstract of whose Paper has been given in the Proceedings of this Institution.[2] It is therefore unnecessary to deal with the question mathematically.

[1] Vol. vi., pp. 203–12.

[2] *Vide* Minutes of Proceedings, Inst. C.E., vol. l., pp. 302–6.

It is well known that all magneto-electric machines, when set in motion by a current, induce in themselves, as electrical systems, currents opposing the motive current. For example, when a current from some source is directed into the coils of a dynamo machine, the coil commences to revolve. Immediately it commences to revolve, it also begins to act as a generator, and sets up a current which is opposite in direction to the motive current, and subtractive from the strength of the latter. The current-strength from the source is, therefore, at a maximum when the second machine, or that driven by the current, is at rest. From consideration, it is easily obtained, that the greatest work is to be yielded by the second machine when the strength of the current given by the first machine, or source, has been reduced to one-half by the induced current from the second machine. With these machines it has been generally found that the current-strength is proportional to the velocity or number of revolutions of the cylinder; so that, supposing two equal machines arranged for the transmission of power, the amount of work reclaimable from the second machine will be 50 per cent. of that employed upon the first, and the number of revolutions of the armature of the second machine corresponding to the maximum of work reclaimed will be half the number made by the first.

Figs. 12 to 14, Plate 1, show curves drawn through six points, from results actually obtained. The revolutions of the cylinder of the second machine are represented as abscissæ, and the work reclaimed as ordinates. The numerical values are given in the following table:—

RESULTS of EXPERIMENTS with DYNAMO MACHINE for the TRANSMISSION of POWER by the ELECTRIC CURRENT.

Fig. 12. Machine No. 95 at 1,100 Revs., driving No. 104.		Fig. 13. Machine No. 95 at 1,100 Revs., driving No. 96.		Fig. 14. Machine No. 95 at 1,400 Revs., driving No. 96.	
Revolutions of No. 104.	Per cent.[1]	Revolutions of No. 96.	Per cent.	Revolutions of No. 96.	Per cent.
1,008	27	884	34	1,199	39
730	36	808	43	1,031	44
584	38	767	44	863	48
501	39	625	45	691	49
420	37	481	39	500	37
359	35	385	32	..	..

[1] Percentage of work reclaimed.

The departures from the theoretical values are somewhat marked, but are within the limits of error that occur with this class of measurements, made with no great attempt at accuracy.

The experiments were made in two ways. In the first arrangement, dynamo machine No. 1 was driven from a steam engine. This was coupled with No. 2 machine by leading wires, the + terminal of one machine to the + terminal of the other, and − to −. A Prony's dynamometer was applied to No. 2 machine to measure the power transmitted. The power expended on the first machine was found by diagrams taken from the cylinder of the steam engine while the first machine was driving the second, and when not. The results of these observations were compared. But the following is a more exact method of measuring the power required to drive the first machine, the power expended being measured from the leather belt, by a dynamometer similar in principle to the ordinary dynamometer used on board cable ships to indicate the strain on the cable:—A pair of loose pulleys of equal diameters are mounted in one frame with their axles parallel and coupled together by links. This frame of pulleys is placed on the driving belt, so that the pair of pulleys contract the belt between them, the two parts of the belt making a given angle. The frame may be held in position by guide-rods, but must be capable of moving at right angles to a line drawn through the centres of the driving and driven pulleys. The position of the frame is marked when the machines are at rest. When the machinery is in motion the movable frame with the loose pulleys will be raised or depressed by the driving side of the belt, because the strain will be greater on that part. Sufficient weight is added to the frame to bring it back to the position of rest. Then the angle through which the belt is depressed being known, as well as the weight, the strain on the two parts can be readily calculated, and the difference in the tensions on the two parts obtained; thus giving the power required to drive the dynamo machine. The three sets of results quoted were obtained by this method.

The Effect of Circuit Resistance on Efficiency of Transmission.

In order to ascertain the effect of resistance in the circuit connecting the driving and driven machines, two machines were connected by leading wires having resistances of ½ unit, 1 unit, and 1½ unit respectively. The machines were two of the smallest Siemens type, and gave without inserted resistance an efficiency of 44 per cent.; with ½ unit resistance added to the circuit the

efficiency was reduced to 38 per cent., giving a loss of ·6 per cent.; with 1 unit of added resistance the efficiency fell to 32 per cent., giving a loss of 12 per cent.; and with 1½ unit added resistance the efficiency was 26 per cent., giving a loss of 18 per cent. The experiments clearly proved that the loss of efficiency is proportional to the added resistance.

Applications to Electro-metallurgy.

The employment of the currents of magneto-electric machines for electro-typing and electro-plating has long superseded the voltaic current. But the production of currents of great quantity and effect has necessitated the use of magneto machines of large size, so that the separation of metals from their ores and their purification by electrolysis have not been practically or economically successful. It is, however, only on a large scale that the current from a dynamo machine can be employed with advantage, since in operating on a small scale the removal of the electrodes from the baths or vats occasions so great an alteration of external circuit resistance, which in its turn, by reason of the amount of current in the inducing electro-magnet being also altered, reacts upon the amount of current developed, so that the maintenance of a sufficiently constant current is impracticable. For the case of small electro separations or depositions, the magneto-electric machine shown in Figs. 9 and 10 has been constructed. This machine, with 900 revolutions of its wire cylinder per minute, and with an expenditure of ½ HP., gives 7 ounces of copper per hour with a single pair of large electrodes. In its construction permanent magnets, as shown, are substituted for the electro-magnets of the dynamo machine, the apparatus being simply a magneto-inductor with no accumulative action.

For the deposition of large quantities of metal, where by changing baths in succession little change is made in the total circuit resistance, the dynamo machine gives much greater economy. With one of these machines it has been found possible, with a proper succession of vats, to deposit as much as 3 tons of copper daily.

Experience has shown that the arrangement of a number of vats in series gives a certain maximum weight deposited, and that when this number has been reached it is still possible to increase the amount deposited by adding baths in parallel circuit, by which addition, the resistance in circuit being reduced, the extension of the series in circuit can be adverted to. How far this extension

may be made appears to be a consideration of the amount of surface it is possible to put with practical effect into the circuit. This portion of the subject being better suited to the consideration of the electro chemist than to that of the engineer, its further detail is beyond the limits of this Paper. A glance at the lists of patents granted by the Patent Office will indicate how numerous are the applications, in chemistry and metallurgy, of currents of the character of those produced by dynamo machines.

The communication is accompanied by a series of diagrams, and small scale drawings from which Plates 1 and 2 have been reproduced.

The electric light was exhibited after the reading of the Paper.

Dr. SIEMENS said, although the Authors were connected with him in business, the Paper had been written without reference to himself. It set forth correctly the scientific principles upon which the action of the dynamo-electric machines and the electric lamps were based, and stated in moderate terms the results that had been practically arrived at. For years past the marvels of the electric light had been spoken of; but it was only within the last year that effects had been produced which would bear comparison with other practical methods of obtaining light. The most remarkable results had been realised, by the experiments extending over six months, at the South Foreland by Dr. Tyndall and Mr. Douglass, the Chief Engineer of Trinity House. A careful analysis of the amount of the light, its nature, its permanency, and the conditions under which it was produced by different machines, had resulted in the recommendation of the most approved machine for extended application to lighthouse purposes. In estimating the power of a new agent of that kind, it was safer to go to first principles and see what consumption of coal was necessary to produce a given effect of light, and to contrast it with the amount of coal consumed in burning oil or gas. This could be done by comparing the results obtained by the Trinity House engineers, with the well known facts as regarded gas light. The electrical machine produced, with 1 HP., 1,250 candle power, at the South Foreland. What, then, was the amount of coal used in generating that amount of light? It would in an average engine be 3 lbs. of coal. Therefore, 1 lb. of coal elicited by the electric machine 417 candle power. In lighting by gas 6 cubic feet of gas gave 18 candle power if the gas was fairly good, so that 417 candles would be equal to 139 cubic feet of gas. A ton of coal yielded 10,000 cubic feet of gas, so that 30 lbs. of coal would represent the 139 cubic feet of gas necessary to furnish the same amount of light afforded by the electric candle with 1 lb. of coal. There was, therefore, apparently a comparison of 30 to 1; but with gas, after allowing for the heating of the retorts, &c., half the weight of fuel might be considered as returned in the form of coke; therefore 15 lbs. of fuel were actually consumed in producing the amount of luminous effect that could be obtained in the case of the electric light with 1 lb. of fuel. He did not say that practical illumination could at once be effected at that enormous difference of cost. The Authors of the Paper had given the data of actual working results, which were already sufficiently favourable. Hitherto, however, the light had been exhibited on a small scale; but, in order to institute a fair comparison, it should

be carried out on a somewhat similar scale to that of gas lighting. He believed in time electric light stations would be established within squares and large blocks of houses. A 100 HP. engine would be sufficient to supply conductors for a large number of lights, and they could be increased indefinitely.

The second question brought forward in the Paper was that of the transmission of power, which, although new and untried, was one of considerable interest. By electrical transmission of power, an amount of from 40 to 50 per cent. was recovered at the end of the line. By putting one such machine to work with an expenditure of, say 3 HP., a power could be produced and utilised at a distance not exceeding half a mile or a mile, according to the size and length of the conductor, equal to nearly one-half that amount. If at certain stations, 100 HP. were so exerted, it would be possible to distribute over a town power which would be exceedingly convenient and free from the dangers and troubles attending caloric motors, and with an expenditure of fuel certainly not greater; because, although perhaps only 40 per cent. of the power exerted at the central station was actually obtained at the further station, it was nevertheless obtained at a very low rate. A 100 HP. engine, economically constructed, would produce 1 HP. with less than 3 lbs. of coal; whereas a small motor of 2 or 3 HP. would consume probably 6 to 8 lbs. of coal per HP. per hour. Bearing that difference in mind, the magneto-electric engine would be an economical one. How far the principle might be applicable ultimately, for the utilisation of such natural forces as water-power from a distance, remained to be seen. The difficulty was in regard to the length of the electrical conductor. Its resistance increased in the ratio of its length; and as the increased resistance would mean loss of useful effect in the same proportion, it would be necessary to double the area of the electric conductor in doubling its length, in order to maintain the same ratio of efficiency; but if that were done, the resistance might be increased to many miles, and he believed profitably, without further loss of power.

He desired to direct attention to the dynamometer employed in the experiments to ascertain the power consumed in the magneto-electric machine which received the power of the engine (Fig. 15). The first experiments, made by indicating the steam-engine with the machine on, and with the machine off, gave very imperfect results; but a dynamometer had been contrived which he thought was of sufficient interest to be brought before the Institution. The belt that drove the machine was nipped between two pulleys, which rested in a slide and were held by a spring adjustment and screws.

If the resistance increased, one side of the belt tended to become straight, and it could not become straight without pulling in the slack side of the belt; but it was held back by the elastic pressure on the slide crossways, which indicated the amount of force necessary to pull the strap straight; and that simple indication, multiplied into the number of revolutions, gave the absolute measure of the power transmitted. The want was often felt of such means of telling how much power a machine consumed. It was not sufficient to say, "If we stop it we shall see how much power the steam-engine indicates, and how much it indicates when working;" because between the two there was the friction of the machine, and there were all sorts of disturbing elements to be taken into account. With the dynamometer in question the measure was direct and absolute. While the machine was taking its power it indicated the amount of power without loss. In that way it was possible to get accurate results. The Authors had stated that one-half of the power was necessarily lost. It was remarkable how nearly the best experimental results had come up to the maximum. He believed that 49 per cent. had been actually realised. He was not sure whether the theory in question held good, that the maximum effect was produced when the velocity of the machine that received the power, and gave it off at the further station, was only one-half of the velocity of the motor. He was under the impression, after some consideration, that about two-thirds of the velocity would give the maximum result. The subject, however, was too new to speak positively on so intricate a point. Enough, he believed, had been said to show that this method of electro-lighting and transmission of power was more than a mere speculation; and that it had entered the ranks of practical application of natural science.

Mr. Gregory, C.M.G., Past-President, desired to ask Dr. Siemens a question. Electric lights had been known for many years. He had always believed one of the great difficulties attending their use for ordinary purposes was the unsteadiness and flickering of the light, owing to the difficulty of finding homogeneous electrodes, the distance of which from one another could be maintained exactly equal. He had observed considerable flickering in the light exhibited, which, if it were used for ordinary purposes, might be rather distressing. He should be glad to know whether this arose from the motor being at some distance, and whether the difficulty was one that could be surmounted?

Mr. W. Atkinson asked Dr. Siemens to state the approximate cost of the machine.

Dr. SIEMENS said he believed the flickering of the light was due to imperfection in the carbons. No doubt if the moving power at the distant station were uncertain, if it should vary in speed, there would be cause for irregularities in the working, but at present the carbons were the most imperfect portion of the whole arrangement. They had been much improved, but were not yet perfect. The difficulty, however, he thought, was not an insuperable one. With care and attention homogeneous carbons would no doubt be produced. Every now and then foreign matter, when it came to the front, would cause a little explosion and a little separation in the piece of carbon, and so occasionally a flickering. In order to light a room electrically, at least two electric candles ought to be used, so that the flickering of the one would melt away, as it were, in the steadiness of the other. The room in which the meeting was assembled was very unfavourable for electric lighting. The screen put up to intercept the rays was an imperfect one, and would allow a large portion of the luminous rays to pass through. If there had been a whitewashed ceiling, and the light were spread over its entire surface, the steadiness and intensity of the light would have been much greater. With regard to the question of cost, he believed the price of a machine of the size exhibited was about £70, and the cost of the lamp was £15. The estimate, however, did not include the conductor, the value of which would vary with the length, but it would not form a material part of the total expense.

Mr. W. H. BARLOW, Vice-President, inquired whether by, what was called, the electric candle greater steadiness of light was obtainable, and if so, whether it was accompanied by any disadvantages?

Dr. SIEMENS replied that this inquiry had reminded him of an omission of the Authors in not mentioning the attempt made to modify the electric light in such a way that it assumed the form of a candle. Mr. Jabloschkoff, a Russian gentleman, had overcome the difficulty of approaching the two carbons from end to end mechanically, by placing them parallel to one another, with an intervening layer of kaolin, or of ordinary plaster of Paris. By placing them in that way, the points were ignited and consumed one with the other, and as they were consumed they could still maintain their absolute position in space. There was, however, one inconvenience inseparable from that mode of arranging the carbons, namely, that the current must continually change from right to left, and from left to right, otherwise the carbon on one side would be consumed at the expense of the other. In order to burn both

sides equally, the current had to change continually, and that mode of working with a reversed current was less economical than working with a continuous current. Whether, notwithstanding that drawback, the electric candles would come into general use remained to be seen. The mode of lighting which had been exhibited was due to a suggestion by the Duke of Sutherland. He had stated to the Duke that the difficulty with regard to the introduction of electric lights was to prevent the glare, and his Grace said, "Why not throw the light up to the ceiling?" The method exhibited was the result of that suggestion, and he believed it was an exceedingly good way out of the difficulty.

Dr. TYNDALL observed, through the Secretary, that were the experiments at the South Foreland repeated, the results would probably be found still more favourable to Siemens' machine No. 68 than those recorded in the printed report. From the first he was struck with the admirable performance of this handy and compact piece of apparatus. Its moderate cost was greatly in its favour, while the power of more than doubling the photometric intensity by coupling two machines together rendered it particularly valuable for lighthouses. He believed the idea of thus using the machines in pairs was first realised during the experiments at the South Foreland. The photometric methods there employed were well calculated to secure accuracy in the comparison of lights so intense. From the variation of luminous intensity Mr. Douglass was able to infer and establish the important influence exercised by the external circuit in the generation of the light.

The process by which the discovery of Faraday had been rendered available for lighthouse purposes consisted of a series of steps, each marking a sudden and considerable advance. The earliest of these steps was unquestionably taken by Mr. Holmes, who produced the first magneto-electric light ever used in a lighthouse. His original machine, though cumbrous and defective compared with those now in use, did good service for many years at Dungeness. As regarded constructive perfection the machines of the Alliance Company were greatly in advance of the first machines of Holmes. The step taken by Mr. Wilde was one of great importance, showing as it did how electric power, from small beginnings, might be vastly accumulated. In Wilde's arrangement the current from a small magneto-electric machine was sent round an electro-magnet, between whose poles revolved an armature covered with copper wire. The currents obtained from this armature greatly exceeded in strength that of the

original magneto-electric machine. This strengthened current, moreover, could be either utilised directly or employed to excite a second electro-magnet, from which still stronger currents could be obtained. With a view to reporting on the subject to the Royal Society, he made a special journey to Manchester, and witnessed there the performance of Wilde's machine. At the time it was astonishing. He might add that Mr. Wilde employed the "Siemens armature" referred to by the Authors of the Paper, which contributed greatly to the power of his apparatus.

In Gramme's machine scientific insight and mechanical skill were very successfully incorporated. By using as an armature a soft iron ring rotating between the poles of a magnet, and surrounding the ring by a succession of coils, the ever-shifting magnetism of the iron was made a copious source of induced currents in the coils. M. Gramme thus applied pre-existing knowledge in a highly judicious manner. For industrial purposes his machine invoked the aid of the principle now to be referred to, and the discovery of which marked an epoch in the development of this question.

That discovery was made almost, if not quite, simultaneously by Dr. Werner Siemens and Sir Charles Wheatstone. Abandoning the use of a magneto-electric machine as used by Wilde, and without invoking a succession of electro-magnets, they succeeded in generating from perfectly infinitesimal beginnings enormous amounts of electric power. In their instruments an armature carrying a coil of wire revolved between the poles of an electro-magnet endowed with the feeble residual magnetism hardly ever absent from iron. Currents of infinitesimal strength were first generated in the wire surrounding the armature; these currents, instead of being carried away, were caused to circulate round the electro-magnet. The power of the magnet was thereby increased, the increase of power immediately reacting upon the armature and making its current stronger than before. These strengthened currents again circulated round the magnet, which in its turn brought its augmented magnetism to bear upon the armature. Thus, by a series of interactions between the magnet and the armature, the former was rapidly raised from a barely perceptible magnetic strength to complete magnetic saturation. In this condition it generated the currents which produced the extraordinary effects observed with the machine of Siemens. The idea of the inventor had thus been worked out to a literally brilliant practical realisation.

He ought perhaps to mention that Mr. Alfred Varley had written to him urging his claims to the invention of the dynamo-electric machine. Into this discussion it was not his purpose to enter. The discovery of Dr. Siemens and Sir Charles Wheatstone was publicly brought before our highest scientific society, and it was to be regretted that Mr. Varley, having, as alleged, hit upon so capital an idea, did not make it known in some similar way. It was also to be borne in mind that the distance between the first formation of an idea and its successful realisation for practical purposes was sometimes very great indeed.

He had limited his remarks to the consideration of the machine as a producer of light. But the other sections of the Paper, and more especially that headed "Transmission of Power to a Distance"—a subject also treated by M. Gramme—were interesting in the highest degree. He would add in conclusion that before many weeks had elapsed he hoped to see one of Dr. Siemens' small machines permanently established in the Royal Institution.

M. Alfred Niaudet remarked, through the Secretary, that he did not agree with Dr. Siemens as to the importance of the distinction between dynamo-electric and magneto-electric machines. In all these instruments mechanical power was converted into electricity by the action of magnetism; consequently all were both magneto-electric and dynamo-electric. Moreover, all the old frictional electrical machines, and the Holtz, were dynamo-electric, as they generated electricity through the agency of mechanical power. The invention of M. Gramme comprised two marked improvements in magneto-electric machines—the novel arrangement by which currents were produced by means of a soft iron ring, and the collecting of the currents, so as to make a practically continuous current. He had applied a similar system to a Clarke machine, and had used ten or twelve bobbins, instead of the two generally composing the typical Clarke machine. This machine was patented in France in December 1871. It had been described by M. Fontaine,[1] and in the "Telegraphic Journal."[2] It was after this that Von Hefner Alteneck introduced a magneto-electric machine, in which the chief novelty was the supply of a continuous current by the collecting process devised by M. Gramme. M. Lontin, who was later in the field, had modified his machine, and had succeeded in producing a very good source of electricity

[1] *Vide* Éclairage à l'Électricité, p. 74. Paris, 1877.
[2] *Vide* vol. iv., 1876, p. 100.

by following with great perseverance the principle he had first made known. He could not admit, as stated in the Paper, that "in all electro-magnetic apparatus, wire coils not acted upon inductively tend to set up opposite self-induced currents;" nor that the Gramme machine was inferior to the Von Hefner Alteneck machine. He believed that in all such machines, if two currents were created in contrary directions, so as to neutralise each other, no expenditure of mechanical power was incurred in the production of these virtually existing, but practically non-existing, currents. A good illustration of this principle was afforded by driving a Gramme machine with an open circuit. The currents in the two halves of the ring were opposed and neutralised, and no resistance was presented by the machine. If now the circuit was closed, the currents in the ring at once became active; and resistance was immediately opposed to the driving power. Consequently, if reverse currents were created in the wires inside the Gramme ring, their production cost no driving power. Again, he did not see how such currents could be brought about; on the contrary, he was able to perceive how these wires were protected against the reverse currents mentioned in the Paper. In that respect the only difference between the two machines would be in the total weight of copper wire used. If the quantity of wire at the two ends of the armature of the Von Hefner Alteneck machine was taken into account, the difference was very little in its favour. From these observations he did not mean it to be inferred that the invention of Von Hefner Alteneck was not a clever one; he admired it sincerely. He believed that the practical value of the Gramme machine lay in the great number of parts into which the wire of the ring and the commutator were divided. M. Gramme commonly separated the ring of his instrument into eighty coils; when the collecting brush escaped a coil, the spark elicited was extremely feeble, and sometimes invisible; consequently the wear and tear of the commutator were inappreciable in the hands of careful men. Von Hefner Alteneck could not well put so large a number of separate divisions in the wire of his machine; and therefore the sparks at its commutator were more vigorous than in the Gramme machine; so much so that after a time the commutator had to be replaced, and ingenious contrivances had been adopted to facilitate the renewal of the commutator. This point would be still more evident if it was considered that, by reducing the divisions of the wire to two, the commutator would revert to exactly what it was in the old Clarke machines. The Gramme commutator, used by

Alteneck, was simply the general solution of a problem, of which a particular solution had been long devised, that was the redirecting the currents as from a single source of electricity.

Mr. S. A. Varley observed that he had devoted much time to the subject of the conversion of mechanical force into electricity. He believed this was the first occasion on which a public discussion had taken place on dynamo-electric machines. The subject was a most interesting one, both from a scientific and from a practical point of view. He considered it a matter for regret that, when a comparatively new method of producing electricity had been brought before the Institution for the first time, no detailed description had been given of the leading dynamo-electric machines in use, and the main points in which they differed from one another. Although the Paper was of considerable length, it contained little about the machines themselves, and those who, like himself, desired to be instructed on the point, naturally felt some disappointment. He proposed to give the conclusions to which he had been led by experimental research, and as far as possible to state the reasons for adopting them. The great impetus of late to the production of electricity by the expenditure of mechanical force was principally in consequence of the discovery of the reaction principle of magnetism; this enabled tempered steel magnets to be dispensed with and to be replaced by soft iron ones, which became more powerfully magnetic when the machines were set in motion. The Authors had stated that Messrs. Siemens patented a dynamo machine in 1867 which worked on that reaction principle, and further that that principle, which was an important step in advance, was discovered independently by Dr. Werner Siemens, Sir Charles Wheatstone, and himself; but the priority of discovery was ascribed to Dr. Werner Siemens. That, he ventured to say, was not correct. It was, as Dr. Tyndall had said, a matter of regret that Mr. Varley did not publish an account of his machine at the time it was made. He had made an effort to finish it for the British Association meeting at Nottingham, in August 1866. The application for the patent to which the Authors had referred was dated January 31, 1867; but the discovery of Messrs. Siemens naturally took place some little time before they lodged their specifications. Dr. Siemens had stated, in a published letter, that his discovery was made in December 1866, when, to use his own words, Dr. Werner Siemens and himself were startled by the fact that a considerable current was the immediate result of imparting motion to the machine. The discovery became the subject of Papers in Berlin on the 15th

of January, and before the Royal Society on the 14th of February. Mr. Varley had deposited his provisional specification, in which the machine was fully described, on the 24th of December, 1866; and allowing the time which Dr. Siemens had claimed for himself, he thought he had the good fortune to be a little beforehand. It had been stated that the last step, which had yielded to modern science the present intensely powerful machines, was the disuse of the commutator for changing alternate currents; and the disuse of such a commutator had been associated with Von Hefner Alteneck's system. It had been further stated that the Gramme was not an original system, but a modification of a machine invented by Pacinotti in 1863; and the Authors had also devoted a paragraph to an account of what was described as the latest construction of Siemens' dynamo-electric machine. He might state generally that the conclusion at which he had arrived was, that Nature always performed the same operation in one uniform way; that the mechanical force consumed in the machines was converted into electricity through the medium of a series of electric and magnetic reversals; and as those reversals were, as far as was known, necessary elements, and occurred in all dynamo-electric machines, whatever description of commutator might be employed, there was not necessarily any special virtue in a particular class of commutator. It was not his province to defend Gramme's invention, as he had a machine of his own; but he contended that the Authors had strained a point in discrediting the originality of that invention. The Gramme machine preceded the Von Hefner Alteneck system by three years; and the commutator used in that system was a distinguishing feature of the Gramme machine. He should like to ask in what the latest construction of the Siemens machine, as described, differed from the Von Hefner Alteneck system, and in what respect the Siemens machine, apart from what was due to Von Hefner Alteneck, differed from the Gramme? The only difference he could see, was that in the Siemens machine the internal iron cylinder revolved, which improved its construction mechanically, and incidentally increased the power of the machine, because the insulated wire was closer to the iron cylinder; but theoretically, whether the internal iron cylinder revolved or was stationary, he believed made no difference. The wrapping the insulated wire on the iron cylinder was, however, an approach to the Gramme machine.

He desired to say a few words with respect to the way in which the electric force was produced in dynamo-electric machines. Electricity and magnetism had often been described as sister forces,

but in many of the phenomena presented by them they were strikingly different. About the time his machine was constructed he had also made a magneto-electric machine for a special purpose, and he observed that less power was expended in giving motion to it when electric force was being generated than when the circuit was open. That appeared to him to be somewhat anomalous; but knowing that Nature had no anomalies, he investigated the subject, hoping thereby to obtain a fresh scientific departure; and he was not disappointed, as it led to the construction of his present machine. The conclusion at which he had arrived was that magnetism and electricity differed in this, that magnetism was a more sluggish force than electricity. In other words there was less resistance to electric than there was to magnetic polarisation. In the machine to which he had referred, the reason why less force was required to impart motion to the machine, when electricity was being developed, was because what might be termed the electric equivalent required less force for production than its equivalent in magnetism.

Mr. WERDERMANN said the Authors had stated that in the Gramme machine "a principle is employed, described by Pacinotti in 1863, of whose apparatus the present Gramme machine is a modification" (ante p. 5). He did not believe they had any intention to depreciate that machine, but he desired to say a few words with regard to Pacinotti's claim. When Gramme's machine first became known, a good deal of jealousy was excited, and he endeavoured to ascertain how far Dr. Pacinotti was justified in his claim. He had entered into correspondence with him, and had received various papers on the subject, and he believed Dr. Pacinotti himself acknowledged that the Gramme machine gave a more powerful current than could be obtained with his machines. The ring used in his electro-magnetic engine was solid iron, with which it was impossible to obtain currents of great intensity. The chief feature in the Gramme machine was that the ring was composed of soft iron wire. With a ring of massive iron the magnetism was too slow, and when the speed of the machine exceeded one hundred revolutions per minute, there was no current whatever. But with a soft iron ring the magnetism moved with great velocity. Having patented the Gramme machine in England and in the United States, he had been a good deal annoyed and injured by the statements of Mr. Wilde in the Journal of the Franklin Institute, in which an attack was made upon the machine based upon the claim of Professor Pacinotti. With a view of putting an end to the contest, he gave permission to any one in

the United States to make Pacinotti's machine, but intimated that he should proceed against any infringement of the Gramme machine.

Dr. HOPKINSON thought it would add to the value of the Paper if the resistances of the different machines were compared, if the electric resistances of the coils were stated, and, better still, if the resistances of those of the armature and of the electro-magnets were given separately. It would also be interesting if the electric resistance of the arc were given. How did the resistance vary with the size of the carbon? Was it constant with the same carbons, or did it vary with the intensity of the current? He should be glad to know whether any direct experiments had been made to determine the electro-motive force of the machines. It was worth remarking (he did not know that he had anywhere seen the observation) that it was possible to deduce an approximation to the electro-motive force of a dynamo-electric machine from a knowledge of the resistance of the whole circuit, and of the HP. required to drive it. Taking proper units, the electro-motive force would be equal to the square root of the product of the HP. and of the resistance. That proposition might be easily proved. It had only to be remembered that the HP. would not be precisely that required to drive the machine, but that a deduction must be made for the friction of the machine, and for loss due to the time during which the coils and the armature coil were short-circuited. It might also be proved that in the case of a magneto-electric machine with permanent magnets, the HP. absorbed in driving the machine would be proportional to the square of the number of revolutions. Of course in a machine like that of Siemens or of Gramme, that would not be precisely the case, for as the current increased the magnetism of the electro-magnets would increase, and, consequently, at all events for low velocities, the power required to drive the machine would increase in a greater ratio than the square of the number of the revolutions. The comparison of the power required to drive a large Gramme machine at different speeds served to verify that deduction. It would be found that the power did increase in a ratio somewhat greater than the square of the number of revolutions. The Paper was not quite clear on the question of the transmission of power by means of two dynamo-electric machines. He wished to know whether the percentages given in the table (ante p. 21) were reckoned upon the power required to actuate the driving machine when the second machine was standing, or upon the power to drive the first machine at the time of the particular experiment. What M. Mascart had proved

(and his theory was a simple deduction from the discoveries of Dr. Joule, Sir W. Thomson, and Professor Helmholtz), was that in a magneto-electric machine—taking a theoretical case in which there was no friction and no loss other than that due to the circuit itself—if the number of revolutions of the first machine were kept constant, the greatest efficiency would be attained when the number of the revolutions of the second machine was nearly equal to that of the first; in that case the efficiency would be nearly perfect, nearly equal to unity. But he also proved that when the greatest amount of power was given off by the second machine, it would make half the number of revolutions of the first machine, and then the first machine would require half the power to drive it which was required when the second machine was standing, and of that power one-half would be transmitted by the second machine. That was a very different thing from the conclusion that the maximum efficiency was one-half. The Paper contained a comparison of the economy of producing light by dynamo-electric machines, and by burning gas in an ordinary burner. It would be interesting to look at the question from a slightly different point of view. Given, 100 cubic feet of gas per hour, in what way could it be made to produce the greatest amount of light? If consumed in ordinary burners he supposed it would produce rather more than 300 candles' light. On the other hand, if burned in a gas engine used to drive a dynamo-electric machine, the engine would generate about 3 HP.; and it had been mentioned what number of candles' light the Siemens machine could produce from 3 HP.—upwards of ten times what could be obtained by burning the gas direct. Again, ½ gallon of paraffin per hour would generate something more than 700 candles' light. If ½ gallon of paraffin per hour were burnt in a petroleum engine to produce power, he believed that nearly 5 HP. would be obtained from it, and with 5 HP. many times 700 candles' light could be obtained. Bearing in mind the great optical advantages for lighthouse illumination of the electric arc over other sources of light, he thought the conclusion would follow that when and where it was expedient to erect apparatus for making gas for lighthouse illumination, it was still more expedient to erect a dynamo-electric machine, and use the electric arc. It would be exceedingly useful if some experiments could be made which would compare the amount of energy actually generated or developed in a gas burner of a particular size and in the electric arc, and which would also show the quantities of different kinds of light generated in the two sources. It would be found that a much larger portion of the

energy generated by the latter agent would be in the form of luminous radiation, which would affect the eye; and to that, he thought, was really due the great efficiency for illumination of the dynamo-electric machine.

Mr. COWPER asked what was the percentage of the loss of light due to the use of a good white reflector similar in principle to that exhibited. He thought the loss must be considerable. The method, however, was an admirable one, of which the Duke of Sutherland, who suggested it, might well be proud. He did not quite see how the apparatus with such a reflector could be applied in the streets, but that was a matter for future consideration. The electric current could be sent to a moderate distance, but long wires gave great resistances. He did not know whether the comparison of the cost of gas and of the electric light had been based on the use of the reflector or taking all the rays of light into account. He imagined from what Dr. Siemens had said, that the whole of the rays were taken and the result compared with gas, the cost in that case being about one-tenth; practically in other cases it was one-fifth. There was only one other point to which he wished to allude. Whenever large soft iron magnets or electro-magnets with wire round them were used, and it was desired to change their polarity quickly, there was always a certain amount of residual magnetism left in the bar; the magnets would not fully discharge themselves of the one polarity and take up the other as quickly as could be desired, and thus in changing the poles when revolving rapidly a certain amount of magnetism was left. He had ascertained that in 1837, when making some small electro-magnetic machines. He then altered the revolving bar, which had only given 1,200 revolutions, and made a bar of thin plates, thirty in ½-inch, riveted together. With this he obtained 2,500 revolutions per minute, showing that the residual magnetism was very slight. The poles of the magnet altered very quickly as they passed the changing apparatus; but it was necessary to give considerable lead to the apparatus to effect the change quickly enough. A somewhat similar plan though not so good had been adopted in many recent machines. In some of the machines a bundle of wires was used instead of thin plates; but wherever it was wished to change the magnetism quickly, it was desirable to have thin plates instead of a large bar.

Mr. DOUGLASS observed that the experimental trials recently made at the South Foreland were for the purpose of determining on the dynamo-electric machine best adapted for service at the Lizard lighthouses, which would shortly be lighted by elec-

tricity. The trials were made with four Holmes's magneto-electric machines, a magneto-electric machine manufactured by the Alliance Company of Paris, two Gramme machines, and two Siemens machines. Of these the latter were certainly the simplest in construction and the most compact, economical, and efficient. The only point at which wear and tear were likely to occur were at the commutator and brushes; these were, however, simple in construction and easily replaced, yet he would suggest that attention should be specially directed to this part of the machine for further improvement. It was considered, before the experiments in question, that alternating currents were best adapted for lighthouse illumination, but it had been found that, with a direct current a condensed beam of light was obtained from the carbons, which was steadier and more economical. With alternating currents the ends of the upper and lower carbons were pointed and consumed at an equal rate, but there was a continual shifting of the voltaic arc around the points, causing variations in intensity. With the direct current, by keeping the negative carbon a little in front of the positive carbon, the voltaic arc was held in one position, and a condensed beam in one direction, of great steadiness, was produced. Considerable uncertainty had generally attended the photometric measurement of the electric light, but with the method adopted at the South Foreland, at the suggestion of Dr. Tyndall, with the six-wick oil lamp of 722 candles as the unit, and a "Bunsen" photometer 100 feet long, the light was measured with as much certainty as ordinary gas flames were measured by the candle. The certainty of measurement permitted the determination for the first time of the loss of light from resistance of the circuit with the conducting wires 694 feet long. That was a matter which would require careful consideration when the current had to be sent through great lengths of wire. The quality of the carbons employed was a matter of considerable importance. Some of the carbons at present manufactured were certainly more homogeneous than formerly, and thus gave a steadier light. In the lamp specially designed for the Lizards one important improvement was the great length of the carbons. The upper carbon was 16 inches long. Hitherto the carbons had not been more than 8 or 10 inches long. Not more than half the length of the upper carbon could be consumed, on account of the intense heat and risk of melting the holder; when it had been burned about half its length, it was replaced as a lower carbon, where it could be consumed to within 1½ inch of the end. There was thus only a waste of 1½ inch on the

16 inches, instead of, as before, on every 8 or 10 inches. With reference to the comparative powers of electricity and gas, he had been requested, five years ago, by her Majesty's First Commissioner of Works, to conduct some experiments at the Houses of Parliament relative to a signal light for the clock tower.[1] Those, he believed, were the first experiments made in England for determining that point. There were already on the premises a steam engine and boiler for the electric light, and the gas was supplied under contract—Cannel gas, of an illuminating power of 25 candles, at *6s. 3d.* per 1,000 cubic feet. The cost of the necessary apparatus and the interest on capital had been calculated in each case, and for the electric light the consumption of coal and the cost of attendance had been included. One of the first Gramme machines brought to England had been used in the experiments. The electric light produced by this machine gave an intensity of 3,066 candles. For the gaslight, the burners of Mr. Wigham, of Dublin, were used. The burner of 108 jets gave an intensity of 1,199 candles, but it was proposed to use three of these burners, giving an intensity of 3,597 candles. The cost of the lights per hour was 67*d.* for the electric, 61*d.* for the 108-jet burner, and 114*d.* for the three 108-jet burners, or in the proportion of 100, 92 and 170. The cost of lighting per candle per hour came out as 100, 234 and 145. That was an illustration of the perfection of the electric spark in a dioptric apparatus for lighthouse illumination. The initial intensity of the electric spark was 3,066, and that of the 108-jet gas burner, 3,597; but the light utilised in a dioptric apparatus for fixed light was equal to 56,721 candles in the case of the electric light, and only 41,365 in the case of gas. The cost of light from a dioptric apparatus for fixed light per standard candle, as proposed to be used, would have been as 100 to 233. With the recent improvements in dynamo-electric machines, there would be still further economy in the use of the electric light. He was of opinion where powerful lights were required that there would be considerable economy, even taking the cost of machinery into account, in the use of the electric light as compared with gas.

Mr. Preece said he was neither the inventor of an electric light, nor the patentee of any dynamo-electric machine, but was present simply as a student to learn all he could of one of the chief duties of an engineer—the application of one of the great forces of nature to the wants of mankind. Much had been said of the dynamo-electric machine, and something of the electric light,

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[1] *Vide* Parliamentary Paper, No. 103, April 20, 1874.

but there was a great deal yet to be learned on those subjects. He was sorry to have to notice omissions in the Paper, which, nevertheless, he regarded as a useful contribution to the knowledge of the application of electric light to practical purposes. No doubt the introduction of the Siemens armature marked an epoch in the history of electric science, and it had been the means of introducing very largely the application of electric light to useful purposes. The Paper, however, did not state the strength in absolute measurement of the electric current that produced the light, and therefore no proper comparison could be drawn between the energy consumed in the boiler of the engine and the energy evolved in the application of the light. It was all very well to compare the strength of a light with an arbitrary standard like a Carcel lamp or a sperm candle; but it would be far better to state in scientific absolute units the energy that was lost or dissipated in filling a hall like that in which the meeting was assembled, or in illuminating the English Channel. Such a point was not difficult to arrive at, and he hoped that when the result of the experiments at the Lizard lighthouses was made known, a comparison would be instituted between the actual energy lost in the light and the energy consumed in the boiler. An important element in the introduction of the electric light was the influence that it might have upon the health of workpeople occupied in large establishments. At the Post Office there was a large hall occupied in the transaction of telegraphic business, where between the hours of 4 P.M. and 8 P.M. in the winter, when gas was burning, a staff of six hundred persons was employed. Those six hundred persons consumed 1,800,000 cubic feet of fresh air per hour, and in order to enable them to carry on their duties there were three hundred and eighty-three gas-burners, which consumed in the same period 3,791,000 cubic feet of air. If by the application of the electric light, which consumed no air, nearly 4,000,000 cubic feet of air could be preserved, what a public benefit would be thereby accomplished! One of the greatest advantages which he saw in the introduction of the electric light was the possibility of its adding to the hygienic properties of buildings. What was wanted, was not a flickering light like that exhibited, but a steady, incandescent, non-combustible light, which required no attention. An effort had been made in that direction in Paris, and he had hoped M. Niaudet would have given some particulars about it. It would be remembered that when the Jabloschkoff light was exhibited in London in the summer of 1877, the effect was so marvellous that the value of most gas companies' shares

fell 10 per cent. In that light two pieces of carbon, which were the terminations of the wires from the dynamo-electric machine, were set vertically and separated by kaolin. A layer of carbon was placed across the upper surface of the kaolin, and then lighted, and the action was so intense that the kaolin and the carbons gradually consumed as wax, forming a process almost, though not really, of combustion. The light was steady but imperfect, for it only lasted, according to some experiments in Paris, an hour and a half. It also threw out an acrid unpleasant gas, but that had been remedied to a certain extent by the introduction of plaster of Paris in place of kaolin. That, he thought, marked a second epoch in the history of the electric light, and it only remained for some one to pursue the subject further to produce a steady non-combustible light.

An interesting point had been mentioned in the Paper, namely, that when two Gramme machines were coupled together in parallel circuit, light effects were produced exceeding the sum of the light effects separately given by each machine. The same effect was produced in the case of the Siemens machine. One machine gave a light intensity represented by 4,464, and another gave a light intensity represented by 6,563, the sum of the two being about 11,000; while the machines coupled parallel gave an intensity of 13,179, being an increase of nearly 20 per cent. A somewhat analogous phenomenon had been observed in regard to the application of electricity to telegraphic purposes; and by a somewhat similar process the rapidity of action of telegraph instruments had to a great extent been increased. By coupling two instruments in parallel arc, the rate of speed had been increased 25 per cent. A Wheatstone receiver joined up in series gave a speed of 80 words a minute, but when united, or coupled in that way, it gave a speed of nearly 100 words per minute. That arose from the fact that when the machine was connected in series an antagonistic current was set up, which reduced the strength of the first current. When the machines were coupled in the way described, there was still an opposing current in each coil; but the current of one coil was opposite in direction to the current in the other; hence they neutralised each other; the effect of retardation was thus destroyed, and an increased speed was the consequence. The same effect doubtless was present in the Gramme and Siemens machines, and led to their improvement when joined in parallel arc. He had lived long enough to remember the use of the old oil lamps and the advantage that was derived from the introduction of gas. He

hoped that he should live long enough to see the streets of London and other towns illuminated by the beautiful light such as was exhibited.

M. Hippolyte Fontaine observed, through the Secretary, that it was impossible, at a short notice, to send complete information in reply to the Paper which had been read before the Institution on Magneto-Electric Apparatus. He would therefore confine himself to calling attention to certain points which had been altogether ignored by the Authors of the Paper in question. 1. The Gramme machines tried at the South Foreland were of a primitive type, quite different to those made now, and an injustice had been done in comparing them with the machines of another maker, who sent his latest pattern. 2. M. Gramme actually made continuous current machines weighing only 200 kilograms (440 lbs.), and feeding three regulators, having each 4,000 candle-power, or a total of 12,000 candle-power. This was a complete novelty, for never until now had it been practicable to supply several regulators from the same continuous current. The lights given were very steady, and separate and distinct one from the other. 3. M. Gramme had also devised a new alternating current machine, measuring less than 0·5 cubic mètre (·654 cubic yard), which supplied sixteen Jabloschkoff lamps of 600 candle-power, thus giving a collective power of 9,600 candles. This machine would be set to work at the Sorbonne, at the Conference to be held under the auspices of M. Jamin, a member of the Institute. 4. The Gramme Company had at the present time delivered five hundred machines for lighting purposes, which were in regular work to the satisfaction of the persons who employed them. No other maker had set to work a tenth part of that number. This fact alone went further to prove the superiority of the Gramme machine than all the theoretical arguments and all the eulogies produced in favour of any other system. Proofs could be furnished in support of these remarks, and should the Institution choose to nominate a commission to verify their accuracy, M. Fontaine would be prepared to place himself entirely at its disposition.

Mr. Higgins said during a recent visit to Paris he had, by the courtesy of the directors of the Société Générale d'Eclairage Electrique, been enabled to see in actual operation a large number of electric lights, and to measure the intensity of the light, and the power absorbed in its production. They employed the magneto-electric machine of the Alliance type, which was somewhat similar to the Holmes machine, and the Jabloschkoff candles. In the

Alliance system the heat of the electric arc was utilised to render incandescent an earthy oxide placed between two parallel carbons. That added considerably to the light, and admitted of several lights being introduced into a single circuit. Several systems were adopted, some of which were not of much practical value. The best results as to colour and intensity of light were obtained from candles with plaster of Paris wicks. With a four-disk Alliance machine making 840 revolutions per minute, and 7,680 changes of polarity in the magnets, the light produced in 3 candles in the same circuit was equal to 3,086 standard wax candles. The HP. absorbed in their production was 1·8 per hour. The original kaolin candles of Mr. Jabloschkoff, of which exaggerated accounts had appeared in the scientific journals of this country, gave an extremely unpleasant light compared with the new ones, and the light was only equal to 450 standard candles from each electric candle, for an absorption of ½-HP. per hour. He had seen from three to five lights in one circuit at a time. That rather contradicted the statement of the managing director of the Gramme Company, that such a result had never been achieved before. The lights had an intensity varying from 300 to 1,500 candles. If a gas-heated boiler were employed to raise steam for the purpose of driving the machines required to produce the Jabloschkoff light at a cost of 100 cubic feet of gas per HP. per hour, the electric light elicited would be five times as great as that which could be created by the gas, if burnt under the best possible conditions for the direct production of light; and if it were correct that gas engines would develope a force of 3 HP. per 100 feet of gas consumed per hour, the electric light generated indirectly from the combustion of the gas would be equal to fifteen times the light which the gas itself could produce. The lights were steady and almost noiseless, so that there was no necessity to have a second light to hide the imperfection of the first. He did not think so good a return of electricity had been obtained for the force employed with the Alliance machine as with the Siemens machines; but the power of the Alliance machine might be increased considerably, without adding to its bulk, by interposing in the exterior circuit a condenser of sufficient capacity. The discharge stored up in the condenser would pass back through the bobbins of the generator upon the fall and reversal of potential in the circuit, thus adding, without extra cost of machinery, to the quantity of electricity which the machine was capable of producing. Mention had been made of cavities, which caused some obscuration of the light, in the carbons of the

electric lamp at the South Foreland. That might be remedied by employing carbons formed of a hard core of graphite surrounded by softer carbon. The more rapidly burning exterior would leave a point of hard carbon always exposed to the utmost energy of the electric arc. He wished to ask the Authors whether the electrolitic deposit of 3 tons of copper in a day had been effected with an evolution of oxygen at the anode, or by oxidising copper at the anode, and deoxidising only at the cathode. If the former, it was an enormous result; but if the latter, only a feeble electric effect would be required to disturb the equilibrium of the copper in solution.

Mr. DOUGLASS had omitted to mention, in his previous observations in connection with magneto-electric machines, the falling off in the intensity of the light with machines having permanent steel magnets. During the twelve years that the Holmes machines had been employed at the Dungeness lighthouse, a considerable falling off was found to occur in the intensity of the light; but, unfortunately, there were no means of arriving accurately at the amount. When the electric light was established at the South Foreland four Holmes machines were employed, and an experimental machine was obtained from the Alliance Company of Paris of about the same power. Experiments were made to determine the intensity of the light from each machine, the HP. absorbed by each, and also the attractive force of the magnets. Last year, after the machines had been at work for five years, the experiments were carefully repeated, and it was found that the intensity of the light of the Holmes machines had diminished about 22 per cent. and of the Alliance machine about 10 per cent.; and the attractive force of the magnets and the HP. absorbed by each machine had been reduced in the same proportion. This would appear to suggest the necessity, in using magneto-electric machines provided with permanent steel magnets, of occasionally remagnetising the instruments. He presumed that no such falling off could occur with the electro-magnets of the Siemens or Gramme machines, but perhaps Dr. Higgs would inform the members on that point.

Mr. J. N. SHOOLBRED said Mr. Douglass had referred to the table of the photometric experiments carried out at the clock tower of the Houses of Parliament. The table referred to the amount of light issuing "from a dioptric apparatus for a fixed light in the most illuminated plane"; and the second and third columns of it referred to gas light. Allusion was made to one 108-jet burner and to three 108-jet burners; and he wished to

know how the photometric expression of the triple light had been arrived at. In the case of the naked flame he presumed it was by multiplying by three the intensity of ordinary light; but in the case of "the most illuminated plane" (which he surmised would mean the refractory belt of the dioptric apparatus) the same proportion did not seem to be preserved. With regard to the Jabloschkoff candle, he wished to know if there was any mode by which the necessity of constantly attaching it to a machine with an alternating current could be avoided, seeing that there was a loss in the amount of effective electricity obtained in that way. During his own observations upon several systems of electrical lighting, he had noticed that the steadiest light had always been produced with alternating currents; whilst the light created by currents in one direction was liable to flickering. Perhaps, therefore, the advantage of steadiness in the light of the Jabloschkoff candle might be purchased at the expense of the diminished amount of effective electricity, which it was said attended an alternating system.

Mr. R. H. BRUNTON desired to make a few remarks on the application of the electric light to lighthouses. Ostensibly the best light was the most powerful one; but that principle was subject to considerable modification. The mariner did not require what had been described as a beautiful light. He did not need a dazzling brilliancy, or anything between that and mere visibility. A light was efficient to him when he could see it and could make out its distinguishing characteristics. Too much light was objectionable in many ways. It prevented a mariner forming so correct a judgment of his distance from it as he otherwise would, and it obscured all objects between, which was especially objectionable when a vessel was obliged to steer for it. There might be said to be three conditions of weather under which a light was shown: in fine weather, in fogs, and in what had been called the ordinary forms of thick weather. In fine weather the electric light was too brilliant, and its effect was dazzling and objectionable. The ordinary method of illumination would transmit the light, in a moderately clear atmosphere, as far as was possible, on account of the practical limit in height for a light and the rotundity of the earth. A height of 200 feet was the utmost limit, and one of 150 feet was given by most lighthouse authorities as the proper height in this country for a light of the first order; this enabling it to show 15 or 20 miles. At that distance a first order light when it emerged from the horizon appeared bright and strong, indeed, it generally illuminated the horizon line before it showed

itself. Mr. Alan Stevenson, he believed, calculated that a first order light would appear more than 100 miles off in an ordinary clear atmosphere. No light would penetrate fogs, and sound was then the only guide to the mariner. In thick weather, such as in rain, haze, or mist, if the electric light would show through it in such a way as its brilliancy would lead one to suppose, or even better than the present method of illumination, it would be an incalculable advantage, because on the coasts of the United Kingdom thick weather was almost the normal condition of the atmosphere. That was the crucial test for the application of the electric light to lighthouses. In 1867–8, he was present at some trials made at Granton by the Scotch Commissioners of Lights with the electric light. A first order lamp was tried beside one of Wilde's electric machines. In fine weather the brilliancy of the electric light was so great as to throw a dark shadow at 5 miles distance; but in rain, while steaming across the Frith of Forth, the electric light was always lost first. That was not on an isolated instance, but was the invariable experience of those conducting the trials. The same thing had occurred in the trials made with Wigham's gas burner at the clock tower of the Houses of Parliament, when a Gramme machine and the 108-jet gas burner were tried side by side. In the early evening, when it was clear, the electric light outshone the gas burner; but, later on, when the atmosphere became thick, the gas was the only light visible. Dr. Siemens had given an explanation of this apparent anomaly in the discussion on Mr. Chance's paper on Optical Apparatus in Lighthouses: "If light might be regarded as a vibratory motion of the medium through which it was transmitted, any obstructive matter in the form of haze or smoke must exercise a destructive effect according to the square of the energy of vibration, or intensity of the light. If that were the case, it followed that a brilliant light would in an obstructive medium soon subside into a light of moderate intensity, and thence proceed at a more equal rate of diminution with light proceeding from a less brilliant source but of equal magnitude, the latter being chiefly determined by the extent of light-emitting surface. . . . . He therefore thought the quantity of light emitted was of more importance than its intensity in seeking distant effects, a circumstance which had not perhaps been fully considered in estimating the relative value of the electric light, as contrasted with the ordinary optical apparatus of extended surface."[1] To sum up, therefore, in fine weather the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxvi., p. 550.

electric light was not wanted; in fogs it was useless; and in thick weather it appeared to be inefficacious.

Dr. SIEMENS said he had been quoted against himself, and he had certainly ventured to express the opinion referred to, because he had at that time made a few observations upon the electric light then established at the South Foreland; and in observing it on the way from Dover to Calais, it seemed to diminish much in the same ratio as the light of the oil lamp diminished; but there would still remain the difference in favour of the more intense light. If it possessed the same volume—lit up the same area of lenses—its greater intensity would carry it to a greater distance; although he had ventured upon the supposition that the obstruction to that light would be greater on the part of matter suspended in the air. Such might be the case; and yet, as was now known, that there was in the electric light a much greater volume than in the ordinary oil or candle light, it still followed that the electric light would, with its greater volume and greater intensity, penetrate to a much greater distance.

He desired to add a few explanations with reference to the transmission of electric power to a distance, whether for the production of light or for the production of force. The Paper stated that the weight of the conductor would increase as the square of the distance; but that proposition, although true in itself, would, if it were accepted, lead to erroneous ideas with regard to the power of transmitting force to a distance exceeding perhaps ½ mile. In order to get the best effect out of a dynamo-electric machine there should be an external resistance not exceeding the resistance of the wire in the machine. Hitherto it had been found not economical to increase the resistance in the machine to more than one Ohm; otherwise there was a loss of current through the heating of the coil. If, therefore, there was a machine with one Ohm resistance, there ought to be a conductor transmitting the power either to the light or the electro-magnetic engine not exceeding one Ohm. If, instead of going 1 mile, it was desired to go 2 miles, it would be necessary first of all to employ a conductor twice the length, but that conductor would give two Ohms resistance, and would therefore destroy much of the effect. To bring it back to one Ohm resistance it would be necessary to put down a second wire, or to double the area of the first; and in that case there would be a wire of twice the length and twice the area, therefore four times the weight and four times the cost. That pointed to an increase in the cost and in the weight of the conductor in the square ratio of the distance. But one circumstance

had been lost sight of in the calculation—that having twice the area to deal with a second generator could be put on, and electricity enough to work two lights could be sent through the double area to a double distance. The moment that was done the conductor was increased, for the power was transmitted only in the proportion of the increase of the length; but that was not enough. The electric conductor did not resist the motion of electricity in the same manner as a pipe resisted the flow of liquid through it, but an Ohm's resistance was an Ohm's resistance for a larger as well as for a smaller current flowing through it, which resistance was only increased by a rise of temperature in the conductor. This rise of temperature was kept down by dissipation of heat from the conductor; or considering that the longer and doubled conductor would possess four times the amount of surface for the dissipation of heat than the single and short conductor, it would be capable of transmitting four times the amount of electric current. It might therefore be said that it was no dearer to transmit electro-motive force to the greater than to the smaller distance, as regarded weight and cost of conductor, a result which seemed startling, but which he nevertheless ventured to put forward with considerable confidence. In uniting the two longer conductors into one, the surface would, however, be increased only in the ratio of $\sqrt{2} : 1$; therefore the relative transmitting power between the longer and shorter conductor would, strictly speaking, be increased in the ratio of $1 : 2\sqrt{2}$, or $1 : 2{\cdot}83$, and the longer conductor would be dearer than the shorter per unit of electromotive force transmitted in the proportion of $4 : 2{\cdot}83$.

Sir WILLIAM THOMSON said Dr. Siemens had just brought forward an idea which appeared to him to be quite new, and to be of great practical importance; namely, that the electric light, if there were a sufficient number of lamps, could be produced with equal economy at a great and at a small distance. By way of illustration he would suppose the cost of a central station dispensing by four hundred machines the electric current to four hundred lamps, each at a distance of 1 mile. Taking those four hundred miles of wire and putting them in a line, having four hundred engines in series, and putting the four hundred lamps at short distances from one another, without any change of circumstances, the same effect would be produced at 400 miles as at 1 mile. The question of the heat developed in the wire was, as Dr. Siemens had remarked, the fundamental question with reference to the quantity of metal required to communicate the effect to a distance. It appeared to him that the most practical way of

producing the result would be to put the wire in the shape of a copper tube. Having a copper tube, with a moderate amount of copper in its sectional area, and a current of water flowing through it, with occasional places to let it off, and places to allow water to be admitted for the purpose of cooling; there would be, without any injury to the insulation, a power of carrying off heat practically unlimited. He believed that with an exceedingly moderate amount of copper it would be possible to carry the electric energy for one hundred, or two hundred, or one thousand electric lights, to a distance of several hundred miles. The economical and engineering moral of the theory appeared to be, that towns henceforth would be lighted by coal burned at the pit's mouth, where it was cheapest. The carriage expense of electricity was nothing, while that of coal was sometimes the greater part of its cost. The dross at the pit's mouth (which was formerly wasted) could be used for working dynamo engines of the most economical kind; and in that way he had no doubt that the illumination of great towns would be reduced to a small fraction of the present expense. Nothing could exceed the practical importance of the fact to which attention had been called; that no addition was required to the quantity of copper to develope the electric light at a distance. The same remarks would apply to the transmission of power. Dr. Siemens had mentioned to him in conversation that the power of the Falls of Niagara might be transmitted electrically to a distance. The idea seemed as fantastic as that of the telephone or the phonograph might have seemed thirteen months ago; but what was chimerical then was an accomplished fact now. He thought it might be expected that, before long, towns would be illuminated at night by an electric light produced by the burning of coal at the pit's mouth, or by a distant waterfall. The power transmissible by the machines was not simply sufficient for working sewing-machines and turning lathes, but by putting together a sufficient number any amount of HP. might be developed. Taking the case of the machines required to develope one thousand HP., he believed it would be found comparable with the cost of a thousand HP. engine; and he need not point out the vast economy to be obtained by the use of such a fall as that of Niagara, or the employment of waste coal at the pit's mouth.

As to the transmissibility of different kinds of light through clear or foggy air, that was a matter for experimental investigation. Theoretically it was an exceedingly interesting question. The whole quantity of energy in the vibrations must be the

same, therefore it might be expected that the absorption would be the same, whether the light proceeded from a small surface, as in the electric light, or from a much larger surface, as in oil lamps of lighthouses. But the mode of operation of the vibrations according as the same colour was produced from one or other of the two sources was a question that mathematicians could not solve, and it could only be decided by experiment. Perhaps Mr. Douglass could give some further information derived from experiments as to the relative transmissibility of light of the same colour from a larger area less intense, or from a smaller area more intense.

Mr. Douglass had not made any complete experiments to determine the point to which Sir William Thomson had referred. In his own experience he had always found that two lights, of the same initial intensity and of nearly the same colour, reached practically the same distance. There was not sufficient difference in the colour of the best oil lights and that of the electric light to account for any appreciable difference in their power of transmission through the atmosphere. With reference to the experiments at the Clock Tower, he might state that he was present on Primrose Hill and had the opportunity of observing that the two lights were practically of the same power. When one could be seen, the other could be seen; and singularly enough, through the murky atmosphere of London they appeared to be of the same size, although the gas burner was about 11 inches in diameter and the electric spark only $\frac{3}{8}$ inch. It did not follow because the electric light was so intense that its full power should be wasted in fine weather. At the new lights on the Lizard it was intended to use a single machine in fine weather and two machines in thick weather. In an ordinary murky atmosphere the lights that were intended to reach 15 or 16 miles did not reach more than 5 or 6 miles. If the intensity of the electric light were increased four or five or six times it was possible that under those conditions it could reach 50 per cent. farther. It was of the utmost importance that a light should reach the distance intended whatever it might be.

Sir William Thomson said, for lighthouses, the great adaptability of the electric light to furnish an increase of power when wanted gave it a value which no other source of light possessed. Gas light had also been advocated as being exceedingly valuable in that respect; but when gas light was increased by a great number of gas burners, the optical effect of the prisms and lenses for throwing it in the required direction was disadvanta-

geous, there being nothing like the full advantage of the additional quantity of gas consumed; but in the case of the electric light, the whole area was so small at the greatest that practically none of the optical advantage was lost by increasing the intensity. The value of the electric light was also of great importance in regard to public health. The detrimental character of the fumes of gas in public buildings was well known. There were no fumes from the electric light, and the quantity of heat generated by it was vastly less than that produced by gas or oil for the production of the same light. It had been stated by a previous speaker that the gas employed in an economical gas engine to drive a machine to produce the electric light would produce the same light with one-fifteenth part of the combustion, and that meant not only increased economy but a great advantage in regard to health.

The Hon. R. C. Parsons remarked that nothing had been said with regard to the continuity of the current produced by the Siemens machine. He wished to inquire, whether by extending the brushes further round the contact breaker it would be possible to increase the continuity of the current? He desired also to ask whether it was advisable to work the machine by means of an engine geared directly on the shaft, or to work it with a strap from an engine? It appeared to him that there was a period of oscillation in the light exhibited that possibly corresponded to the revolutions of the engine working the machine. If the machine were worked by a belt the variations in the work would tend to stretch the belt; which would then relax, producing a variation in the angular velocity of the armature, and thus a vibration in the intensity of the light would be produced. The vibration appeared to correspond to a period of about 600 or 700 revolutions a minute. Some time ago he had made experiments with the view of producing a continuous current by a dynamo-electric machine, and he selected a Gramme machine for the purpose. By driving it up to 4,000 or 5,000 revolutions a minute, and having an armature consisting of thirty-two separate coils, he had succeeded in producing a pretty continuous current; but there was great difficulty in keeping the brushes in contact with the contact breaker. If the apparatus was not perfectly true, the momentum given to each hair of the brush was such as to prevent perfect contact with each element of the contact breaker during a revolution; and consequently the number of currents produced would not approach to the revolutions multiplied by the number of coils in the armature. In the case of the Siemens machine the revo-

lutions per minute were considerably less than in the machine to which he had referred; but even with this machine he thought it would be troublesome to keep the brushes in perfect contact with each element of the contact breaker.

Mr. W. A. GORMAN said he had given the system of electric illumination careful attention. It might interest the members to know that the great show room of the "Magasin du Louvre," in Paris, was lit with four lamps, in each of which were placed three Jabloschkoff candles, each candle being supposed to burn an hour and thirty minutes, so that when one candle was consumed, the current was put into contact with the second candle, and so on. The four lamps had globes of ground glass, and the light was diffused without throwing shadows. The method was used in the silk and carpet rooms, the colours being shown as clearly as by daylight. The Jabloschkoff candle required alternate currents so as to burn the two sides equally. The "Place de l'Opera," the office of the "Figaro," the works of the new Grand Hotel, where the men were employed night and day, were also lighted in the same manner. A specimen of the Jabloschkoff candle was upon the table. The small lamp with glass cylinder, also exhibited, was the invention of Messrs. Ladiguine and Koni, and was of novel construction, the principle being the treatment of strips of carbon in a vacuum. By the resistance offered to the current four or more lamps could be put into circuit. The lamp, if modified for the purpose, would be useful for mines where the gases were free. For the many objects to which the electric light was adapted, the submarine electric lamp might rank amongst the most useful. It was a great boon to engineers in constructing submarine foundations, as it enabled the diver to work by night. He exhibited such a lamp, and said the difficulty at first, now, however, overcome, was making the joints watertight, but the burning of the carbons after a few minutes produced a vacuum.

Mr. WERDERMANN remarked that M. Gramme first showed experiments with regard to the transmission of motive power at the Vienna Exhibition, and in 1873 he brought the matter before the Academy of Science, Paris. Subsequently, M. Niaudet published a pamphlet with reference to the Gramme machine, in which he gave the results of practical experiments on the transmission of power, similar to those furnished by the Authors of the Paper. M. Niaudet pointed out that as the Seine was canalised throughout its whole course, some of the weirs would afford great power; that, for instance, at Port-à-l'Anglais the force lost was 3,000 HP., and that it would be beneficial to the community

if only one-third of that amount were conveyed into Paris. Dr. Siemens had directed attention to the fact in an address to the members of the Iron and Steel Institute, but he had called attention only to the utilisation of Nature's powers in matters which were of great interest to the engineer. Mr. Werdermann had himself first shown experiments with regard to the transmission of power, in March 1873, before the members of the Society of Telegraph Engineers, and proposed a long time since to take advantage of the transmission of motive power for the conveyance of power into mines and tunnels. With reference to the opinion of the Authors, that in point of construction the Gramme machine was inferior to the machines described in the Paper, the idea of opposite self-induced currents was inconsistent with the principle of Gramme's machine; that was with the theory of the generation of electric currents by the motion of a magnetic pole inside a solenoid, and that in fact there existed a great similarity between the two machines. Gramme's ingenious mode of collecting the currents had been applied to the Siemens machine, and the sole difference between them consisted in the manner in which the wire was coiled. The trials at the South Foreland were not such as to test the real value of the Gramme machine, because an old model had been employed instead of one with the latest improvements. If Mr. Douglass had informed him that the trials were to be made he would have provided a machine which would have given the greatest satisfaction. Mr. Douglass had stated in his report that the Siemens machine, with an expenditure of 9 or 10 HP., gave a light equal to 14,000 candles. That certainly was a very good result; but the latest Gramme machine, with an expenditure of 5 HP., gave a light of the same intensity; and when the machine was coupled for quantity it gave a light of 25,000 candles. One type of the machine, with an expenditure of 8 HP., gave a light of 25,000 candles, and an expenditure of 13 HP. produced a light of 45,000. He could confirm all the statements made in M. Fontaine's communication. It had been urged that in the Siemens machine the commutator could easily be replaced, which was not the case with the Gramme machine. But this alleged superiority of easy renewal of the commutator was the best proof of the inferiority of the machine. Gramme's commutator did not burn, and therefore did not need renewal.

Mr. Corbet Woodall wished to speak on that part of the Paper dealing with anticipated competition between electric and gas light. The Authors had wisely and with considerable foresight

predicted that there would be separate fields for the two agents. There could be little question that for lighthouses or for signalling purposes, where one light of great intensity was required, the electric light would be found cheap and convenient; but he had little fear that the field of gaslight would be materially encroached upon by the new method. The Authors had clearly established that in order to obtain from an electric light the greatest amount of advantage, it should be used in a limited number of centres of great intensity. In all but the most exceptional cases that would involve a considerable waste, because, in order to have a sufficiency of light at the extremity of the field to be illuminated, there must be great excess at the points nearest to the light. Then in the matter of distribution, with the ordinary gas supply a householder might have the equivalent of 20,000 candles in his house, or reduce it to the equivalent of a bedroom rushlight. Reference had been made to the advantage of the electric light as supplied to railway stations and places of that character. By the present system the light could be turned down as soon as a train had left a station and could be turned on again when another train came in. But that method of economising would be exceedingly difficult and even impracticable without some further improvements in the arrangement of the electric light. Then the plant required would have to be equal to the production of the maximum power required at any particular time. There could be no storage, and for sixteen hours out of the twenty-four the plant must remain idle in order to put forth the whole power during the remaining eight hours. In ordinary gas making the light was manufactured during the whole twenty-four hours, and was stored up during the hours when it was in excess of the demand. He had thought that the distribution would be a source of considerable trouble, as it certainly appeared to be a matter of great expense, looking at the figures given as to the size of the conducting cable; though after what had been stated in regard to the possible conveyance of the power from the pit's mouth to London, he presumed that was an error on his part. But certainly, before the electric light could have any material hold upon the field now occupied by gaslighting, there must be great improvements in the character of the lamps. The light exhibited was, he presumed, an exhibition of the most recent and perfected lamp; and he was quite sure that, what with the noise and the flickering, the members would be glad to return to the ordinary gaslight. With regard to the figures in the Paper, he found it difficult to deal with the hypothetical illustration of

¼ mile radius illuminated from three light centres, his difficulty consisting mainly in the fact that such an experiment had not been tried. There seemed to him, however, to be some material errors in the comparison. Bearing in mind that the light diminished in proportion to the square of the distance, it appeared to him that in order to get a light equal to that of an ordinary gas burner at a distance of ¼ mile, there would need to be, not a third but the whole of the 150,000 candles centred in one place. Taking an ordinary gas burner of 20 candles' power, and assuming it to give a light of such intensity that a person could read small print at a distance of 15 feet, it would be necessary to have a light of 150,000 candles placed at ¼ mile distance in order to give the same amount of illumination as 3,450 ordinary gas lamps distributed at equal intervals. The gas consumed in such a number of lights at 2*s.* per thousand cubic feet (which would include the cost of distribution, wear and tear, and so on) would amount to 34*s.* 5*d.*, as against 22*s.* 6*d.* stated by the Authors. But he would ask whether or not it was supposed for a moment that a light of 150,000 candles could be exhibited in one place with a view to the utilisation of the whole of its power, and yet that at any point near it would not be so unbearable as that a screen would have to be interposed? That seemed to touch upon the weakness of the system commercially. Allowing that a screen had to be interposed, the whole of the difference, and considerably more than the difference, between 34*s.* 5*d.* and 22*s.* 6*d.* would be absorbed. With reference to the illustration taken from Messrs. Siemens's workshops, he was obliged reluctantly to say that it appeared a little disingenuous. In the first place, if 15 per cent. was a fair proportion to allow for interest, wear and tear, and renewals upon gas pipes fixed to walls and with fittings that were rarely touched, it surely was not sufficient to allow that amount upon a machine travelling at the rate of 850 revolutions per minute. In the next place, there should have been added to the cost of the electrical apparatus the cost of the engine power, and of the shaft and straps necessary to communicate the power to the machine. Then, inasmuch as the gas in that case was in competition with the electric light at its cost price, the gas should have been taken at the same rate—at 2*s.* instead of 3*s.* 9*d.* per thousand cubic feet. Again, he had never heard of a case where any shop was at work with gas for one thousand hours in the year, except under the most unusual and pressing circumstances. Five hundred hours more nearly corresponded to the mark. Making corrections upon those points, he brought out the table thus: interest at

10 per cent. upon the cost of fittings, £60, amounted to £6, gas at 2*s.* per thousand feet for five hundred hours would amount to £36, in all £42. Adding £110 for the cost of the engine shafts and belts to £250, the cost of the machines, the total amount was £360. Taking 15 per cent. as a fair representation of interest and wear and tear, the amount would be £54. He assumed that 5 HP. would be required for driving three machines; and taking 4 lbs. of coal per indicated HP., and adding the cost of one man when the machines were at work at 7*d.* per hour, and 8*d.* per hour as the cost of the carbons (according to the two years' experience of a workshop in Rouen), the total was £36 16*s.* The two sums together amounted to £90 16*s.*, or rather more than 2 to 1 in favour of gas. He did not for a moment say, taking the data the Authors had gone upon, and assuming that the whole light given by the electric lamp could be utilised, the figures would be anything like that; but he maintained that gas, or any other method of illumination admitting of division into small light centres, had a considerable advantage over a system like that of the electric light. He did not like to "prophecy without knowing," but he could plead, at least, the contagious example of Dr. Siemens, who foresaw the time when electric light stations would be established throughout large towns, and when gas mains would be replaced by conducting cables. Before such a consummation was reached, probably the cost of the manufacture of gas would have been so far reduced as to lift it even further than at present beyond the reach of competition. He wished to remind the members that gas makers were not simply gas makers. All the products of the coal came into profitable use; and there was a remarkable absence of waste. Before there could be much realisation of the hopes of the advocates of the electric light, there must be some material and radical improvements in their lamps, and in the method of dividing the light. At the same time gas makers were supplying a light at least as economical and far more convenient, and the promise of the future in regard to improvements was as bright in their case as it was in that of their would-be competitors.

Dr. Higgs observed that the cost of gas had been taken in the Paper not at 3*s.* 9*d.* but at 2*s.* per 1,000. It was also expressly stated that the electric light was intended for use in large spaces and not for household or limited requirements. He might be permitted to add an explanation of the way in which the light had been shown on the first occasion when the source of electricity—a dynamo-electric machine—was in King Street, in the printing

office of Messrs. Nichols, to whom, and to their Mr. Gravell, the thanks of the Institution were due. The current had been brought by a conductor 250 yards long, composed of nineteen copper wires stranded, each wire being 0·06 inch in diameter. The same source also served to show the transmission of power, the wires being removed from the terminals of the lamp, and attached to the terminals of a second dynamo-machine, fitted with a Prony brake. The light had been obtained from a single lamp and reflector, and was projected upwards on to the white ceiling-screen, whence the rays were equally diffused over the room. The carbons were in the same vertical axis. In the present instance two lamps were employed, and as it was no longer convenient to use Messrs. Nichols' printing-office, an engine had been placed in the vacant ground at the back of the Institution in Boar's Head Yard. Mr. Cowper had said that the present method of illumination was not adapted for street lighting; but the arrangement might easily be altered to suit this purpose. The light might be placed with advantage close to the horizontal screen, and for lighting larger spaces with this diffused, reflected light, it was only necessary to place the lamp in a cup-shaped reflector, and above this a small horizontal reflector of curvature best adapted to the distribution of the light. Dr. Hopkinson had put some interesting questions, and it was to be regretted the Paper was intended to show only that which had been done practically, and that electric lighting and the transmission of power were no longer confined to the laboratory. The electric resistance of the various parts of the machine, although constant in proportion for each machine, was varied with the resistance of the exterior circuit, and for the purpose for which each machine was intended. The resistance of the electric arc might be taken as about 1 mercury unit, but it varied almost directly with the resistance and number of convolutions of the machine producing the current. Many measures of current passing during transmission had not been made. With a machine having 0·05 unit resistance, a current of 75 rebers through one Ohm had been obtained, with an expenditure of 2 HP. This gave a current of which the mechanical value, when the machine was connected to a precisely similar machine, was 56,000 foot-lbs. with the second machine at rest; and a resultant current of 29,000 foot-lbs. with the second machine in motion, the HP. expended being maintained constant. The work reclaimed, measured on the dynamometer, was 48 per cent., closely agreeing with the efficiency of one-half. As to the effect of circuit resistance on the transmission of power in the instance quoted in the Paper,

the addition of 1½ unit resistance reduced the efficiency to 26 per cent. with the particular machines employed; but if convolutions of wire were added to the cylinder of the machine the efficiency would again attain its maximum. This was not clearly put in the Paper, and it might be thought that 26 per cent. was the greatest efficiency attainable, whereas by bringing the power of the machine, by winding the cylinder with the requisite number of convolutions, to the proper proportion, the efficiency would again rise to its maximum. It should be noted that the theoretical efficiency of 50 per cent. was referred to the use of two equal and similar machines, one used as the driving, the other as the driven machine. It was quite probable that a larger percentage of work reclaimed might be attained by some other arrangement of machines, but such an arrangement had not occurred to him. He had, however, had some opportunities of roughly experimenting, by which he might judge of the effect of driving one machine by two others coupled in series. He connected two small machines in series, and drove a medium-sized machine free, without friction brake. The results of three readings gave, speed of small machines, 1,060 revolutions; speed of medium machine, 1,820 revolutions. The medium machine was then driven by one small machine, with the following results taken from three readings: speed of small machine, 1,060 revolutions; speed of medium machine, 780 revolutions. It would thus be seen that the speed of the medium machine had been rather more than doubled by driving it from two machines coupled in series. The best conditions for work admitted of direct proof. Two equal machines being employed, and a galvanometer put in circuit between them, the deflections showed that when the second machine was at rest, the current was of twice the intensity that occurred when the second machine was giving out its best work. Although of no great practical use, it was interesting, as illustrating a well-known scientific principle, to note that with an electrolitic bath in circuit in which a single metal was dissolved, and deposited from its solution, no work was absorbed by this electrolitic action, provided the electric resistance of the bath was inconsiderable. Work was absorbed in decomposing the salt and depositing the metal, but this work was compensated by the energy of the combination of the solvent set free with the attached electrode. This might be of advantage where power had to be transmitted and metallic deposition effected at the same time. M. Niaudet had made some comparisons with the Gramme machine. He could not agree that it was no disadvantage that opposite currents should

be set up in a machine, because if this did not cause waste of power (which was doubtful), it at least must show that those parts causing those opposite currents were ineffective. Neither did he agree with M. Niaudet as to the advantage of the Gramme commutators. He was aware that Von Hefner Alteneck had made a commutator with fifty-six parts, and he could not see why, supposing the diameter of the commutator increased, a much larger number of parts might not be introduced with the Siemens machine. He believed, however, that the advantage of so finely divided a commutator had not held good with the Siemens machine. That this commutator was of equal, and even superior advantage to that of the Gramme construction, had been shown in the report of the Trinity House, referred to in the Paper. It was a principle of construction of the commutator of the machine exhibited, that it was easily replaced at a small cost, and as it was the only part of a dynamo machine subject to wear or accident, this must manifestly be an advantage. It had been suggested that reference should have been made to the Jabloschkoff candle. But as the Paper referred to dynamo, not to magneto-electric apparatus of recent construction, and as hitherto somewhat an old type of double-current machine had to be employed with those "candles," the mention of their use was omitted. Although the consumption of carbon was greater with the candles than with the lamp, he would not underrate their value; for having seen their use in Paris, in completing the works of the Avenue of the Opera House, he was fully convinced that, with improved apparatus, the day was not far distant when the electric light would be a necessity to the engineer and contractor. Their best thanks were due to Messrs. Siemens Brothers for the use of their machines and for the permission to experiment at their works, as well as to Dr. Siemens for his kind hints and advice.

Mr. Brittle wished to add a few words relating to power transmitted by electricity. The machinery for measuring the power capable of being transmitted by electricity to a distance was arranged as shown in the diagram (Fig 15) to which Dr. Siemens had called attention. He had also explained how the power required by the first dynamo-electric machine was measured, and pointed out that the method of measuring by means of indicator diagrams taken from the cylinder of the steam motor was much more difficult to manage than that they had adopted. They did not place the two movable pulleys in a slide, but carried them on a pivoted frame, which was during each experiment brought back to its zero point by putting weights in the scale. Calling the weight W, the

angle between the belt and a vertical line a, and the tensions on the two parts of the belt T_1 and T_2 respectively, the formula used to calculate the power given up by the belt was

$$T_1 - T_2 = \frac{W}{2 \cos. a}.$$

As the angle a was fixed for all the experiments the calculations were easily and quickly made. This formula did not take into account the stiffness or the friction of the driving belt, and the results were therefore not absolutely correct. It was, however, surprising how very near some of the results so obtained approached the limit, 50 per cent. The power given up by the second, or driven dynamo machine, was measured by a Prony brake dynamometer, precisely similar to the one exhibited, and with a machine of the same size. At the commencement it was necessary to find what position of the collecting brushes would give the best results. A great number of experiments had been made for that purpose, during which it was found that their positions required to be altered as the speeds of the two dynamo machines were altered. The brushes did not make contact with the commutator at the ends of a horizontal diameter, as might at first glance have been expected, but at a point a little further round, in the direction of the armature's motion, say from 20° to 40° from that horizontal diameter, depending on the velocity. The position so selected, and adhered to pretty nearly throughout the set of experiments by which the three curves were obtained, was 22° on one side of the commutator and 38° on the other. For the three curves the speed of the first machine was kept as nearly as possible constant, while that of the second was altered at will by adding weights to the extremity of the Prony brake lever. The weights employed were from 1 lb. to 5 lbs., and the length of the lever 3 feet. As the weights of the Prony brake were increased, a corresponding change in the speed of the second machine was not obtained by shifting the brushes, so that they required fewer readings with the heavier weights. The highest speed of the first machine giving reliable results was 1,400 revolutions per minute. Some experiments were made at 1,500 revolutions, but at that speed the power reclaimed was much less. Whenever sparks were allowed to appear between the brushes or the segments of the commutator the percentage of power reclaimed was considerably reduced. The proper rate of the small machine for giving light was 1,100 revolutions. Upon experimenting with dynamo machines of different

sizes no great difference was observed. The sizes from which the highest percentage, 49 per cent., was obtained were both of the smallest pattern. A machine of that size was capable of giving light equivalent to 1,200 standard candles. That was not the size referred to by Dr. Tyndall and Mr. Douglass as the small machine in the report on electric lights at the South Foreland. That machine was larger than the one with which their experiments were made, and it gave a light equivalent to 6,000 standard candles. It appeared that there was for the highest percentage of power reclaimed a certain relative speed of the second dynamo machine as compared with that of the driving or first machine. That speed appeared to be between one-half and two-thirds of the speed of the first; also when resistances were inserted between the two machines the percentage of power reclaimed varied inversely as the resistance.

Mr. W. H. Barlow, Vice-President, said that the members were greatly indebted to the Authors for their admirable and instructive Paper, and for the trouble they had taken in exhibiting the machines. He wished that the light had been attended with less noise and a little more regularity, but he imagined that those difficulties would in time be overcome. It was most encouraging to hear from Dr. Siemens and Sir William Thomson the extraordinary facilities with which the electric light could be transported to a distance.

Mr. C. Brooke remarked, through the Secretary, that the dynamo-electric machine, which appeared the most available means at present known for evolving a powerful and constant current of electricity, was a striking example of the conservation and transformation of energy; dynamic energy being used up in producing, by the intervention of magnetism, an electric current. This fact, among many others, almost irresistibly led to the consideration of the nature of Magnetism and Electricity. If these were "fluids,"—matter of some kind, the production of either at the expense of dynamic energy, was inconceivable; but if they were forms or phases of energy, the transformation of one form of energy into another was quite in accordance with physical experience. Magnetism was now looked upon by many eminent physicists as a phenomenon of molecular rotation; and many known facts tended to confirm this view. If a copper ball rotated on an axis parallel to the principal lines of force of a powerful horse-shoe electro-magnet, no resistance to the motion was experienced when the magnet was excited by a current, and

no heat was developed by continued rotation; but if the axis of rotation was in any other direction, and notably when it was at right angles to the lines of force, great resistance was experienced, and heat was developed by forced rotation. This was precisely what would happen, in accordance with the well-known dynamical principles of rotation, if the molecules of the ball were compelled to rotate in planes at right angles to the lines of magnetic force; and when these planes were perpetually changing their relations to the plane of rotation of the mass, heat must be produced by molecular friction. Furthermore, the rotation of the plane of polarisation of a ray of light passing through a piece of heavy glass parallel to lines of magnetic force was a confirmatory phenomenon. Light and heat were now generally admitted to be subjective impressions on appropriate receptive organs of sense, produced by the impact of molecular waves; and facts were not wanting which would lead to the inference that electricity was also a phase of molecular wave-motion. It might be sufficient to adduce two such facts—the probable identity of the velocities of light, heat, and electricity; and the close relation of the relative conductivities of heat and electricity in many different metals, as determined by Wiedemann and Franz. It might perhaps be found that in a helical wave, bearing some analogy to a wave of circularly polarised light, the right or left direction of the helix, like the thread of a right- or left-handed screw, might possibly serve to explain the phenomena of positive and negative electricity.

Mr. F. W. Reeves stated, through the Secretary, that he had had six months' experience, in the winter of 1876-7, of the use of the electric light supplied by Messrs. Hopkins, Gilkes, and Co. to the Tay Bridge works. So far as he was aware, this system of lighting large outdoor spaces had been tried to a limited extent only in this country. Two Gramme single machines were employed, each capable of producing a light equal to 1,000 candles, and requiring about 3 HP. to work them. They were driven from a fixed engine by 2½-inch indiarubber bands. The lamps made by Serrin were of the ordinary type, and were connected to the machines by two cable wires, each 300 yards in length. The light was wanted for a large space in the harbour, where various operations were being carried on, such as building the caissons and the brick piers, preparatory to their being floated out, and the erection and rivetting of the iron girders. The extreme range of the works was 400 yards, and, as large quantities of materials were in the way, the lamps were fixed on the cliffs, about 60 feet above the harbour, in "guard-boxes," which could easily

be moved about. They were 300 yards apart, to admit of cross-beams of light being thrown where required. By this means the operations were carried on night and day without difficulty; the bricklayers were enabled to labour, and the ordinary jetty work to be continued during the short winter days without the men's time being reduced, thus securing important advantages to the contractors. The lights burnt steadily, and but little trouble was experienced after they had been properly regulated. The carbons had to be removed every hour and a half. Owing to bad carbons, on two occasions, the metallic holders came into contact before the attendant had time to shut off the current, and they were consequently burnt. The estimated cost of working, including motive power and attendant, but exclusive of the engine-driver, was 1*s.* 5*d.* per hour for each lamp. A shunt was employed for convenience in changing the carbons. He would recommend the employment of two lamps for each machine to obtain a continuous light, the current being shunted from lamp to lamp during the operation of renewing the carbons. There had been no opportunity of testing accurately the power of the light produced; but when both lights were thrown in one direction, a newspaper could be read at a distance of nearly 2 miles. The metallic brushes for collecting the currents were only renewed once during the six months. On one occasion one of these machines was taken to Dundee, to illustrate a lecture, and for more than an hour the current was passed back through the cable without going through the lamp. The machine became overheated and the connections at the end of the coils on the armature were melted. This damage was, however, easily repaired; but the machine was liable to get out of order if the current had direct metallic contact without the resistance given by the carbon points. On another occasion a machine was inadvertently demagnetised during an experiment to decompose water. The two wires were put into water when the machine was working; immediately there ensued a complete stoppage of the electric current, and it was only after several strong currents had been passed from the other uninjured machine that it resumed its normal condition. Experiments with a dynamometer to ascertain what amount of power could be transmitted from one machine to the other showed that one-third of the power was transmitted by the driven machine. The greatest resistance was produced when the armature was brought nearly to a state of rest. This subject deserved consideration, inasmuch as in many cases power might readily be applied in places not easily reached, where a small amount might be required. All who had

witnessed the electric lamps at the Tay Bridge works were most favourably impressed. Mr. Jackson, the contractor, had since employed two sets of similar lights at the Stobcross Docks at Glasgow, and Messrs. Carmichael and Company of Dundee had determined to adopt the electric light at their foundry works. He thought considerable improvement might be looked for in the mechanism of the lamp, which should be self-acting for, say, ten hours without requiring attention.

Mr. T. Wrightson observed, through the Secretary, that at the end of 1876 he purchased and subsequently applied one of Dr. Siemens's dynamo machines and lamps to the lighting up of a large open space used as a bridge-building yard by Messrs. Head, Wrightson & Co., of Stockton-on-Tees. He believed it was the first application of electricity to the lighting up of workshops in England; although in erecting the Tay Bridge Messrs. Hopkins, Gilkes & Co. used a Gramme machine for night-work during the year 1876. His firm used Messrs. Siemens's machines constantly for the first three months of 1877, to enable the men to continue working during the night. Some disadvantage was incurred from the dense shadows thrown, but the remedy for this was to have two or more lights, by which means the shadows were broken up. The dynamo machine was the identical one used by Dr. Tyndall in his experiments at the South Foreland Lighthouse, and was of 1½ HP. It was driven from the bridge yard shafting, and the lamp which was of 1,000 candle power was placed in an elevated position about 30 feet from the ground, and as near the machine as possible. The intensity of the light diminished as the length of the conducting wires increased, although he believed this loss was minimised by making the conducting wires of larger section, so as to reduce the electrical resistance. The convenience of this lighting arrangement was of a value beyond the consideration of cost; but his firm considered that interest on the outlay, superintendence by one man, and cost of charcoal points, was amply covered by the small charge of 1*s.* per hour. The form of reflector to be used was a matter of considerable importance. After trying different forms it was found that in order to reflect downwards the rays passing upwards, and to spread the rays sideways, the best form was that of a parabola crushed slightly flat, and with a long projecting hood at the top to catch the upper rays, the voltaic arc being at the focus of the distorted parabola. The shape of the reflector might be popularly described as similar to the bonnets formerly worn by members of the Society of Friends. Of course the shape of the reflector must

in every case be determined by special considerations; the above was only designed for particular requirements. The lamp, when once understood, was easily kept in order by an intelligent fitter and he might state that the ingenious automatic action of Dr. Siemens' lamp was wonderfully successful and uniform in its working. From the numerous inquiries his firm had lately received for information as to the working of the system he augured that its adoption was becoming general.

January 29, 1878.

JOHN FREDERICK BATEMAN, F.R.SS. L. & E., President, in the Chair.

And

February 5, 1878.

WILLIAM HENRY BARLOW, F.R.S., Vice-President, in the Chair.

The discussion upon the Paper, No. 1,545, "Some recent Improvements in Dynamo-Electric Apparatus," occupied both evenings.

At the Meeting of February 5, the following Candidates were balloted for and duly elected:—William Anderson, Arthur Ayres, Francis Bell, John Blackett, Alan Brebner, Alexander Buchanan, William Errington, Charles Pullar Hogg, Edward Newcombe, Charles Assheton Whately Pownall, and John Avery Branton Williams, as Members; James Abram Arneil, George Attwood, James Barron, Richard Secker Brough, Gustave Adolphe Canet, George Cartwright, William James Chalk, Stud. Inst., C.E., John Thornton Chancellor, William Alfred Dawson, Waynman Dixon, William Eckstein, Jenkin John Evans, John Charles Gill, Stud. Inst. C.E., John Godfrey Hochstaetter Godfrey, Arthur Trethowan Goodfellow, Stud. Inst. C.E., Singleton Goodwin, B.A., Stud. Inst. C.E., Alexander Grafton, Henry Griffiths, Arthur Franklin Guillemard, B.A. Stud. Inst. C.E., Willoughby Hannam, Albert Josiah Hess, Stud. Inst. C.E., William Henry Hodges, William Hodgson, Stud. Inst. C.E., George Gordon Jenkins, James Johnston, Arthur Daniel Jones, William Barrow Kendall, Stud. Inst. C.E., William Walter Kiddle, Captain R.N., Claude William Kinder, John List, Stud. Inst. C.E., Robert Patrick Tredennick Logan, Stud. Inst. C.E., Charles Christian Malsch, George Martin, Arthur Herbert Meysey-Thompson, Stud. Inst. C.E., Herbert Neal, Stud. Inst. C.E., Henry Wilkes Notman, George Henry Ogston, George Willes Ommanney, Robert William Roberts, William Sewell, Walter Parker Smith, George Hurst Stanger, Charles Anthony Stoess, Stud. Inst. C.E., Gerard Philip Torrens, Stud. Inst. C.E., Hamilton Tovey, Captain R.E., George

Kempthorne Watts, Stud. Inst. C.E., and Edwin James White, Stud. Inst. C.E., as Associates.

It was announced that the Council, acting under the provisions of Sect. III., Cl. VII., of the Bye-Laws, had transferred Whately Eliot, George Fuller, William Stuart Howard, Alfred William Morant, and Charles Edward Walker Ogilvie, from the class of Associate to that of Member.

Also that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution:—William Barrington, James Edward Berry, Arthur Robert Beynon, Urban Hanlon Broughton, Robert Dougal, Samuel Haughton Galbraith, Thomas Stephen Lacey, John Henry Douglas Watson, John Woods, and David James Wylie.

February 12, 1878.

JOHN FREDERIC BATEMAN, F.R.SS. L. & E., President, in the Chair.

No. 1,534.—"On the Evaporative Power of Locomotive Boilers."[1]
By JAMES ATKINSON LONGRIDGE, M. Inst. C.E.

THE object of this Paper is to investigate certain questions relating to the evaporative power of locomotive boilers, regarding which there exists considerable difference of opinion. According to some authorities the evaporative power is mainly dependent on the fire-box surface; and they have gone so far as to state, that in general it may be expressed by 2 cubic feet of water evaporated per hour for each square foot of fire-box surface. Others, without going so far as this, hold that, though the tubes have some influence, yet it is only the first 2 or 3 feet next the fire-box which are of value, and that the rest of the tube has but little practical effect. On the other hand, there are the advocates of long tube boilers, who confidently assert that by long tubes alone can economical evaporation be obtained. Again, it has been maintained that the diameter of the tube has a decided effect on the evaporation; and that large diameters are detrimental to evaporation. Then, it is held that the economical effect of the fuel is influenced by various ratios, such as the ratio of the grate surface to the total heating surface, of the heating surface of the fire-box to that of the tubes, and by the rate of combustion, or the weight of fuel burnt per square foot of grate per hour. Lastly, it is stated by some that the combustion of the fuel is practically perfect, whilst according to others a large portion of the calorific power is lost by the escape of carbonic oxide gas unconsumed.

Such are some of the questions on which much difference of opinion exists; and it is remarkable that the advocates of the various opinions all appeal to practical experience in support of their views. In a subject where experience is so extensive, and

[1] The discussion upon this Paper occupied portions of two evenings, but an abstract of the whole is given consecutively.

observers so generally acute, it seems strange that such contradictory views should be held; but when the phenomena are carefully looked into, it is found that there are so many variable conditions to be dealt with, that unless the whole of them can be grasped at once, the observer is almost sure to attribute the result of his observations to a part only of the causes at work, and thus to arrive at a false conclusion. For example, the case may be taken of two engines, one of which burns 150 lbs. of coke per square foot of fire-grate per hour, and the other 50 lbs.; and because it is found that the first evaporates about 8 lbs. of water to each lb. of fuel, whilst the latter evaporates $9\frac{2}{3}$ lbs., the conclusion is arrived at that hard firing is incompatible with economy: the economy, as will hereafter be shown, being attributable, not to the rate of firing, but to the larger amount of heating surface for each lb. of fuel burnt in the one engine than in the other.

In fact, it is only by combining the different variables in a formula that their joint effects can be obtained; and if such a formula be possible, then, by considering the effect of each variable separately, the rest remaining constant, the due influence of each can be traced; and by an examination of the same formula it can at once be seen which conditions have a real influence on, and which are independent of, the result.

There are various formulæ for the evaporative power, all however, so far as the Author is aware, of an empirical character. Probably the best is that by Mr. D. K. Clark,[1] M. Inst. C.E., which is of the form

$$w = a\, r^2 + b\, c;$$

where w is the weight of water evaporated per hour by each square foot of fire-grate, a and b are constants, r the ratio of the heating surface to the grate surface, and c the weight of fuel burnt per square foot of grate surface per hour. It is evident that such a formula as this can only be applicable within certain limits. For instance, if the ratio of the heating surface to the fire-grate be 300, and the fuel burnt be 100 lbs. per square foot per hour, then, taking Mr. Clark's constants for a and b, w = 2349 lbs., or an evaporative effect of 23·49 lbs. of water to each lb. of coke, which is about double what could be obtained.

In order to set at rest these questions as far as possible, the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlvi., p. 247.

Author deemed it desirable to investigate a formula based upon the well-known laws of combustion, and upon the law of transmission of heat through metallic plates, which, though not strictly accurate, is generally admitted to be sufficiently so as to be applied in practice by engineers. This law may be thus expressed:—The quantity of heat transmitted through a metallic plate is proportionate to the area of the plate and to the difference of temperature of the medium on one side from that on the other. The quantity of heat developed by the combustion of 1 lb. of fuel is accurately known, as are also the weight of the gases arising from the combustion and their specific heat. It is also generally allowed that, in order to have perfect combustion, about one-third of the air admitted must pass away undecomposed. The quantity of heat, in units, generated by the combustion of 1 lb. of fuel can therefore be determined; and the disposal of this heat is the problem to be dealt with. Now, the heat is disposed of as follows: first, by radiation from the boiler; secondly, by transmission into the water through the surface of the fire-box; thirdly, by transmission into the water through the tube surface; and fourthly, by loss in the heated gases and unconsumed air escaping through the chimney. The heat lost by radiation in the case of a well-clothed boiler is small, and may be taken into account, under the head of waste, in estimating the calorific value of the fuel.

There remains to investigate the absorption of heat to be ascribed to the fire-box, the tubes, and loss in the gases. This method of examination will enable the evaporative effect of a foot of fire-box surface to be separated from that of a foot of tube-surface, the relative effects of a foot of tube surface at any given distance to be compared with that adjoining the fire-box, and in fact the useful effect of 1 lb. of fuel in any boiler of which the dimensions are given to be predicated, and, *vice versâ*, the dimensions to produce a given evaporation with any required economic effect of the fuel to be determined.

The principle upon which this investigation has been conducted is as follows: Given the consumption of fuel per hour, then the generation of a certain number of units of heat in the fire-box becomes known. Of this a portion, which is determinable, passes through the fire-box surface into the water; the remainder goes to raise the temperature of the gases and the unconsumed air which enter the tubes at a temperature that can be estimated. The quantity of heat abstracted by the tube surface can also be ascertained, and the residue gives the temperature of the escaping gases lost through the chimney.

The investigation of the formulæ which represent these various objects is given in an Appendix, and is as follows:—

$$\text{Evaporation from fire-box in cubic feet per hour} = \frac{S\,m\,x}{N} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (A)$$

$$\text{Evaporation from tubes} = \frac{h\,x}{N}\left\{1 - \frac{1}{\epsilon^{\frac{m s}{h}}}\right\} \quad . \quad . \quad . \quad . \quad (B)$$

$$\text{Total from boiler} = \frac{x}{N}\left\{S\,m + h\left(1 - \frac{1}{\epsilon^{\frac{m s}{h}}}\right)\right\} \quad . \quad (C)$$

In order to use this formula it is necessary to ascertain the value of the various constants.

The first of them, *m*, denotes the transmissive capacity of a square foot of metallic surface, or the units of heat transmitted from the gases inside to the water outside per hour per square foot of surface for each degree of difference of temperature. It has been found that, within the limits of practice in boiler-making, this is independent of the thickness of the plates and of the material of which they are made. The Author had, however, considerable difficulty in satisfying himself of the actual value of *m*. Having recourse to Peclet's "Traité de la Chaleur," he found from experiments on heat transmitted from steam inside a pipe to water outside, that the transmission for each degree of difference of temperature per square foot per hour was—

No. 1 experiment	. . . .	335	units per hour.
„ 2 „	. . . .	315	„ „
„ 3 „	(with the same apparatus)	974	„ „
„ 4 „	„ „	1,020	„ „

It is not easy to account for these discrepancies, but it is certain that such figures are inapplicable to the case of boilers. Peclet, however, states that 1 square mètre of bottom surface exposed to the most violent action of a furnace will evaporate 100 kilogrammes of water per hour, which is about 20 lbs. per square foot, and taking 1,120 units of heat to evaporate 1 lb. of water, this gives a transmission through each foot of heating surface of 22,400 units per hour.

In the well-known experiment made by Mr. Robert Stephenson, in order to determine the relative value of fire-box to tube surface, he found that 1 square foot of fire-box surface evaporated $1\frac{2}{3}$ gallon per hour, or $16\frac{2}{3}$ lbs., which is equal to a transmission of 18,666 units per hour.

Mr. Graham, in an experiment quoted by Mr. D. K. Clark,[1] evaporated 218 lbs. of water per hour from a surface of 10·53 square feet, equal to a transmission of 23,170 units per hour; while, according to experiments made by M. Paul Havrez,[2] the water evaporated per square foot of surface was, with coke 24·5 lbs., equal to a transmission of 26,950 units per hour, and with coal 36·9 lbs., equal to a transmission of 40,590 units per hour. The higher results obtained by M. Havrez are probably due to a more active combustion than was exerted in the other experiments; and the Author is disposed to assume these figures as tolerably accurate for locomotive boilers. But in none of these results was any record taken of the temperature of the fires.

From experiments made by Pouillet the heat of furnaces is stated to be—

At a white heat	2,370° Fahr.
„ bright white heat	2,550° „
„ dazzling „	2,730° „

The Author found many years ago, with Daniell's pyrometer in the fire-box, just at the entrance into the tubes of a locomotive boiler, that the heat appeared to be from 2,400° to 2,450°. Taking Havrez's value of transmission from a coke fire, there is obtained

$$m = \frac{26{,}950}{2{,}450} = 11,$$

or 11 units of heat transmitted per hour by each square foot of surface for each degree of difference of temperature.

The next constant to be determined is U, the calorific value of 1 lb. of fuel. In all the calculations in this Paper coke is the fuel dealt with. The Author thinks it is fair to assume that 88½ per cent. is available carbon, the other 11½ per cent. being allowance for moisture, ash, and waste, including the loss by radiation. As the calorific value of carbon is 14,000 units, U the effective calorific value of 1 lb. of coke = 14,000 × 88½ per cent. = 12,390 units.

The calculations to find w and σ are given in the Appendix. It is sufficient here to say that w, which denotes the weight of the products of combustion and the unconsumed air due to 1 lb. of coke = 17 lbs.; while σ, the specific heat of the mixture of air and gases, = 0·237; therefore $w\,\sigma$ = 4·033. Adopting these constants, Table A has been calculated for nineteen engines, of which the details and performances are given in an earlier Paper by Mr. Clark.[3]

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlvi., p. 242. [2] *Ibid.*
[3] *Ibid.* vol. xii., p. 390.

TABLE A.

1 Names.	Ratios. 2 Surface of Tubes to Fire-box.	Ratios. 3 Total Heating Surface to Grate.	Ratios. 4 Heating Surface to 1 lb. of Coke per Hour.	Evaporation in Cubic Feet per Hour. 5 Per Square Foot of Fire-box.	Evaporation in Cubic Feet per Hour. 6 Per Square Foot of Tubes.	Evaporation in Cubic Feet per Hour. 7 Per Square Foot of Total Heating Surface.	Evaporation in Cubic Feet per Hour. 8 Ratio of 1 Square Foot Box to 1 Square Foot Tube Surface.	9 Lbs. of Coke Burnt per Square Foot of Grate per Hour.	Evaporation in Cubic Feet per Hour. Formula. 10 Fire-box.	Evaporation in Cubic Feet per Hour. Formula. 11 Tubes.	Evaporation in Cubic Feet per Hour. Formula. 12 Total.	Evaporation in Cubic Feet per Hour. 13 Total by Experiment.	Difference of Formula from Experiment. 14 Plus.	Difference of Formula from Experiment. 15 Minus.	Temperature of the Gases. 16 Temperature in Fire-box.	Temperature of the Gases. 17 Temperature of escaping Gases in Smoke-box.	18 Water Evaporated by 1 lb. of Coke by Formula.	19 Water Evaporated by 1 lb. of Coke by Experiment.	20 Water Evaporated by 1 lb. of Fuel by Formula.	21 Water Evaporated by 1 lb. of Fuel by Experiment.
			Feet.												°	°	Cubic Ft.	Cubic Ft.	Cubic Ft.	Cubic Ft.
"Ixion"	7·44	61·1	0·443	0·392	0·2300	0·2488	1·7 to 1	138	38	166	204	201	3	..	2733	1170	0·1105	0·1084	6·906	6·775
"Pyracmon"	10·00	70·0	1·065	0·341	0·1211	0·1412	2·80	69	42	149	191	155	36	..	2505	501	0·1503	0·1218	9·394	7·612
"Great Western"	10·90	76·2	0·960	0·352	0·1322	0·1507	2·60	79	51	209	260	212	48	..	2581	548	0·1454	0·1242	9·087	7·765
"Ajax"	8·76	78·0	0·927	0·349	0·1340	0·1560	2·60	89	38	128	166	153	13	..	2513	571	0·1446	0·1332	9·037	8·325
"Courier"	11·70	80·5	1·070	0·347	0·1200	0·1384	2·90	75	52	211	263	203	60	..	2563	496	0·1485	0·1146	9·281	7·412
"Iron Duke"	12·50	91·7	1·130	0·352	0·1161	0·1334	3·03	82	50	207	257	230	27	..	2574	479	0·1493	0·1335	9·334	8·344
"Snake"	11·70	80·5	0·884	0·360	0·1443	0·1612	2·50	75	27	127	154	152	2	..	2640	596	0·1427	0·1408	8·919	8·800
"A" Y. & N. M.	10·35	74·5	0·564	0·381	0·2024	0·2181	1·88	132	24	132	156	162	..	6	2747	937	0·1231	0·1278	7·694	7·987
"Sphinx"	13·00	115·0	0·734	0·380	0·1700	0·1853	2·23	157	33	192	225	233	..	8	2737	722	0·1357	0·1405	8·481	8·781
Caledonian No. 51	15·70	80·0	1·460	0·353	0·0896	0·1054	3·90	55	18	71	89	84	5	..	2547	399	0·1540	0·1453	9·625	9·081
Caledonian No. 33	15·50	80·0	1·915	0·333	0·0656	0·0818	5·08	42	17	52	69	71	..	2	2420	363	0·1565	0·1610	9·781	10·060
Caledonian No. 13	15·70	80·0	0·744	0·379	0·1702	0·1824	2·23	108	19	135	154	122	32	..	2777	700	0·1358	0·1076	8·488	6·723
Caledonian No. 124	15·70	92·0	1·397	0·351	0·0944	0·1100	3·70	66	22	93	115	99	16	..	2568	409	0·1560	0·1320	9·750	8·250
Caledonian No. 102	15·65	85·3	0·885	0·356	0·1443	0·1570	2·46	93	21	132	153	120	33	..	2685	588	0·1404	0·1100	8·775	6·875
"Sirius"	9·70	62·0	1·409	0·310	0·0873	0·1082	3·55	44	22	60	82	77	5	..	2355	409	0·1543	0·1430	9·644	8·938
"Pallas"	8·85	51·0	1·330	0·317	0·0909	0·1183	3·48	38	26	67	93	97	..	4	2347	422	0·1525	0·1600	9·531	10·000
"Nile"	10·60	67·0	0·957	0·342	0·1340	0·1522	2·55	70	22	90	112	98	14	..	2573	557	0·1454	0·1260	9·087	7·875
"Orion"	8·20	53·4	0·637	0·371	0·1840	0·2044	2·02	84	20	81	101	87	14	..	2703	827	0·1302	0·1134	8·137	7·087
"Queen"	9·75	65·0	0·753	0·359	0·1634	0·1817	2·20	87	23	102	125	106	19	..	2637	700	0·1369	0·1161	8·556	7·256
Averages	11·70	..	..	0·354	0·1365	0·1544	2·60	..	..	..	..	..	..	..	..	..	0·14273	0·12942	8·9266	8·0887

An examination of this table shows that the five Great Western engines, "Pyracmon," "Great Western," "Ajax," "Courier," and "Iron Duke," evaporated by actual experiment from 10 to 29 per cent. below the quantity given in the formula; the Caledonian engines, Nos. 13, 102, and 124, from 14 to 21 per cent. below; and the "Nile," the "Orion," and the "Queen" from 12½ to 15 per cent. below. On the other hand, the four engines, "Ixion," "Snake," No. 51, and "Sirius," averaged 3½ per cent. above, and the "A" York and N. Midland "Sphinx," No. 33, and "Pallas" 3¾ per cent. above; the results of these last-named eight engines being almost exactly the same as the calculated results from the formula.

At first sight the discrepancies in the case of the five Great Western engines, the three Caledonian, and the "Nile," "Orion," and "Queen," might seem to throw doubt upon the formulæ; but a closer examination shows that in all these cases the fuel was doing much less than its duty. For instance, the average evaporation of the eleven engines just named was 7·581 lbs. of water per lb. of coke, against 8·994 lbs. which they ought to have evaporated; whilst in the other eight engines the actual evaporation was 8·830 lbs., against 8·821 lbs., the proper quantity. The deficiency in the Great Western engines, and in Nos. 124 and 102, was no doubt in part due to the small distances between the tubes, viz., ⅜ inch and ½ inch, which prevented any efficient circulation of water, and also in part to the large quantity of fuel burnt per square foot of fire-grate, making it probable that a considerable quantity of carbonic oxide passed away unconsumed.

Mr. D. K. Clark's formula before referred to is, for the coke-burning engines,

$$w = \cdot 0178\, r^2 + 7\cdot 94\, c,$$

where w = weight of water evaporated per square foot of grate per hour from 212°;

c = coke burnt per square foot of grate per hour;

r = ratio of total heating surface (measured inside) to grate surface.

From this the values in the first column of Table B (see next page) have been calculated for the nineteen engines included in Table A. The table contains, in parallel columns, the evaporation

the Author is led to believe that the value of m, as deduced from actual experiments, in which the only uncertainty was as regards the temperature of the fire, cannot be far from its true value for locomotive boilers. If so, it follows, first, that the function of the tubes is a most important one, and that the idea that the evaporation of a boiler may be denoted by 2 cubic feet of water for each foot of box surface is fallacious, and scarcely less so the idea that any fixed ratio, such as 1 to 3, can be upheld as the proper ratio between the fire-box and tube surfaces.

Influence of Length of Tubes.

Much weight has been attached to long tube boilers as conducive to economy. A glance at the formula shows at once that the length of the tube has nothing whatever to do with economy of evaporation:—

$$\frac{x}{N}\left\{S\,m+h\left(1-\frac{1}{\epsilon^{\frac{ms}{h}}}\right)\right\}.$$

The only place where the dimensions of the tubes enters the formula is in the index of ϵ, and there s is the total heating surface of the tubes. But whether there be one hundred tubes of 3 inches diameter and 6 feet long, or one hundred tubes of 2 inches diameter and 9 feet long, or fifty tubes of 2 inches diameter and 18 feet long, the index of ϵ, and consequently the evaporative power, remains the same.

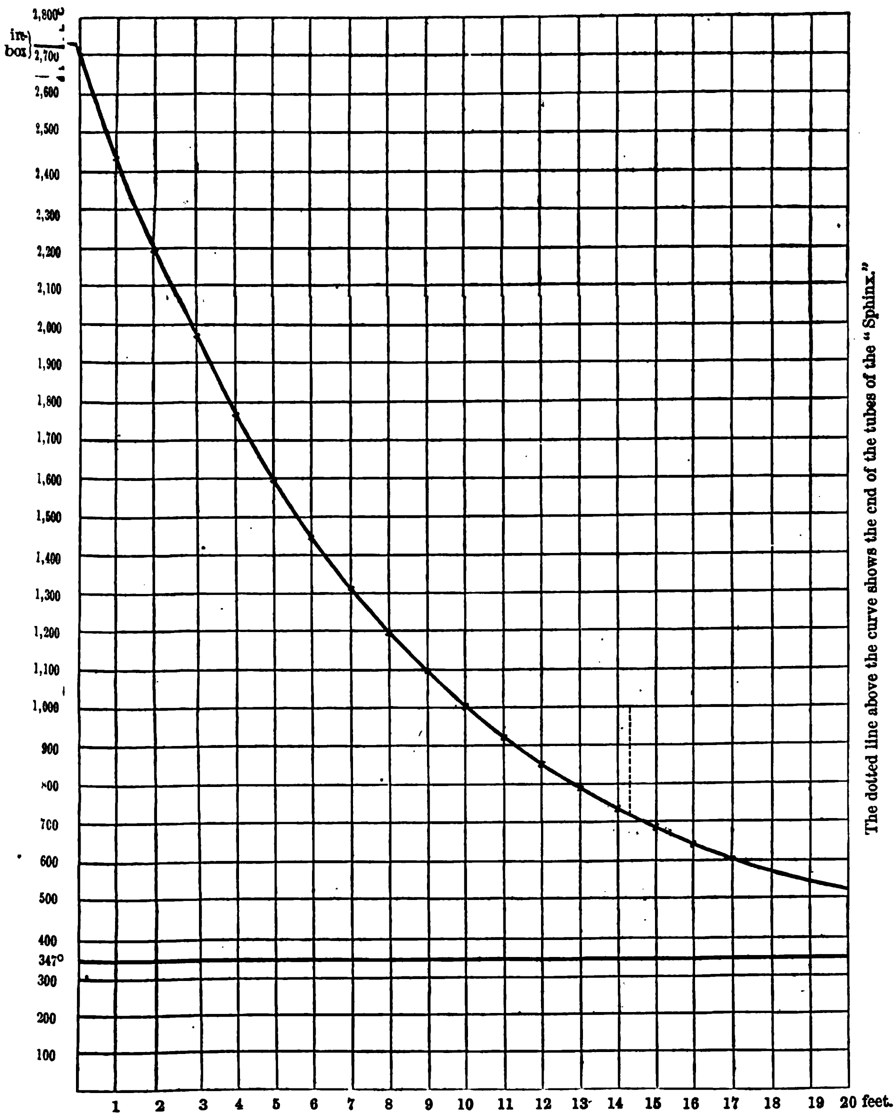
That long tubes *per se* are not conducive to economy is also shown by Table A, in the case of the "Sphinx" and the "Pallas." In the "Sphinx" the tubes were 13 feet 4½ inches long, and the ratio of tube surface to fire-box surface 13 to 1; whilst in the "Pallas" the length of tube was 10 feet 6 inches, and the surface ratio 8·84 to 1. Yet in the latter engine the economic effect of 1 lb. of fuel was 9·531 lbs., against 8·481 lbs. in the former.

Fig. 1 shows the rapid reduction of temperature in passing along a tube. (See next page.)

Influence of Diameter of Tubes.

With respect to this also there has been much difference of opinion. The late Mr. Zerah Colburn stated that, to obtain the same economy from a tube of double the diameter, its length must also be doubled. In order to prove this, he says that the heat of the gas is

FIG. 1.



The dotted line above the curve shows the end of the tubes of the "Sphinx."

DIAGRAM SHOWING THE REDUCTION OF TEMPERATURE IN THE TUBES OF THE "SPHINX."

The abscissæ show the lengths from the fire-box end.
The ordinates show the temperature of the gases.
The temperature of water in the boiler was 347°.

transmitted to the surface of the tube by radiation; that radiation is inversely as the square of the distance, and directly as the quantity (or weight), and also as the temperature and specific heat of the gases. He proceeds to say that in analogy with Newton's law of attraction, the whole heating power may be supposed to be concentrated along the mathematical axis of the tube, and from this he deduces the law, thus expressed by him: "With a reduction of the diameter of the tube the evaporative effect of each square foot of heating surface increases as the square of the diameter." This, perhaps, would be better expressed thus: "The evaporative effects of a square foot of surface increases inversely as the square of the diameter of the tube." His argument is as follows:—Double the diameter of the tube, and the quantity of gases will be quadrupled; whilst the rate of absorption per minute will be only one-fourth of the original rate; or since the heating surface is doubled, the actual amount of absorption per unit of surface will be one-half the original quantity. This appears to be wrong. The heat radiated is not only proportional to the temperature and the surface, and the quantity or weight of the gases, but also to the time of contact. This time is also quadrupled, as well as the area of the tube; and this Mr. Colburn seems to have overlooked.

In the Appendix will be found a note showing how, when all the circumstances are taken into account, the amount of heat transmitted is altogether independent of the diameter of the tube. It may therefore be affirmed that, as regards transmission of heat, the length and diameter of the tubes are a matter of indifference, so long as the aggregate heating surface of the tubes remains the same.

Ratio of Heating Surface to Fire-grate.

On this point much stress has been laid; and it has even been insisted as a rule for practice, that certain definite heating surfaces should be given to each square foot of fire-grate. In point of fact, no such rule can exist. The ratio is not between the absorbing surface and the fire-grate, but between the absorbing surface and the units of heat generated, that is to say, the weight of fuel burnt per hour. An examination of Table A will show that whilst the "Sphinx," with a ratio of heating surface to grate of 115 to 1, evaporated by the formula 8·481 lbs. of water per lb. of fuel, the "Pallas," with a ratio of only 51 to 1, had an evaporative power of 9·531 lbs. of water per lb. of fuel, and similarly with other engines. Comparing, however, the ratio of heating surface to 1 lb.

of coke burnt per hour, with the evaporative effect, there was found at once, as shown in Table C, a concordance of results which

TABLE C.

—	1 $\frac{S+s}{WG}$. Heating Surface to 1 lb. of Coke Burnt per Hour. S.	2 $\frac{\text{Evaporation}}{\text{W. G.}}$. Water Evaporated by 1 lb. of Coke. Formula.	3 Water Evaporated by 1 lb. of Coke. Actual.
	Square foot.	lbs.	lbs.
"Ixion" . . .	0·443	6·906	6·775
"A" Y. & N. M. .	0·564	7·694	7·987
"Orion" . . .	0·637	8·137	7·087
"Sphinx" . . .	0·734	8·481	8·781
No. 13	0·744	8·488	6·725
"Queen" . . .	0·753	8·556	7·256
"Snake" . . .	0·864	8·919	8·800
No. 102 . . .	0·885	8·775	6·875
"Ajax" . . .	0·927	9·037	8·325
"Nile" . . .	0·957	9·087	7·875
"Great Western" .	0·960	9·087	7·765
"Pyracmon" . .	1·065	9·394	7·612
"Courier" . . .	1·070	9·281	7·412
"Iron Duke" . .	1·130	9·334	8·344
"Pallas" . . .	1·330	9·531	10·000
No. 124 . . .	1·397	9·750	8·250
"Sirius" . . .	1·409	9·644	8·938
No. 51	1·460	9·625	9·081
No. 33	1·915	9·781	10·060

is very satisfactory, and leaves no room for doubt, that it is upon this ratio that the economic effect of any given boiler depends.

From the general formula the Author has deduced a formula giving the economic value of 1 lb. of fuel in any locomotive boiler of which the dimensions are known, and from this formula the values in column 2 of Table C have been calculated. These values agree exactly with those in Table A, by dividing the total evaporation by the weight of the fuel consumed per hour. They are also shown in Fig. 2 (see next page), in which it will be seen that the curve of economic effect rapidly approaches to parallelism with the axis.

It may, therefore, be stated, that the economic effect of the fuel in a boiler depends not on the ratio of the heating surface to the fire-grate, but on that of the heating surface to the coal burnt per hour. By this formula the total heating surface per lb. of fuel requisite to obtain any desired economy of fuel may be determined.

Having got the total heating surface, it remains to divide this between the fire-box and the tube surfaces. This may be done in whatever proportions are found most convenient, the ratio between the two having but little result on the economic effect, though not absolutely without influence, as is shown in the Appendix.

Fig. 2.

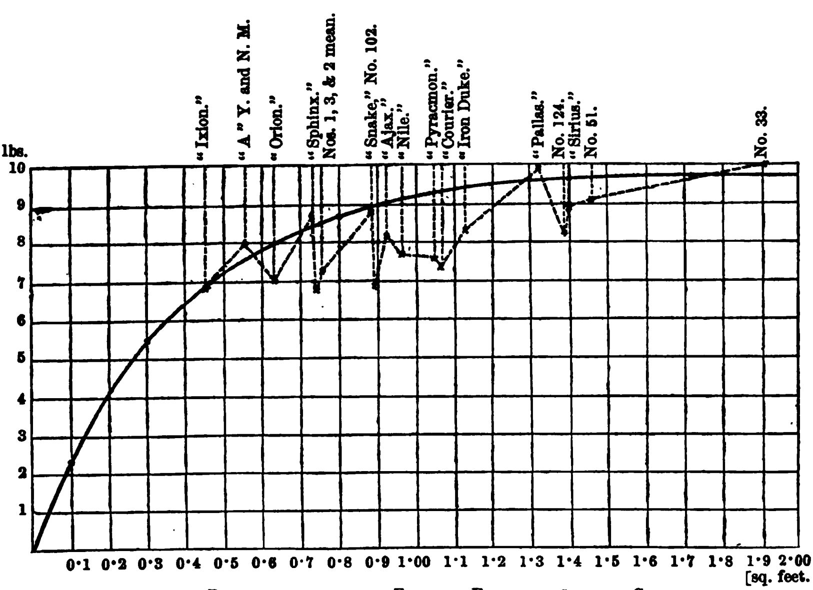


Diagram showing the Economic Effect of 1 lb. of Coke.

The full line was obtained by the formula; the dotted line by experiment.

The abscissæ denote square feet of heating surface per lb. of coke per hour.

The ordinates denote lbs. of water evaporated by 1 lb. of coke, the total evaporative power of coke being taken at 9·82 lbs. of water per lb. of coke.

As an example, take the "Sphinx," which had a heating surface of 0·734 square foot for each lb. of coke burnt per hour; and this surface divided between tubes and fire-box in the ratio of 12·98 to 1, say 13 to 1. The economic value of the fuel in this boiler was 8·481 lbs. of water per lb. of coke. With a boiler having exactly the same heating surface, but in the ratio of 10 feet of tube to 1 foot of fire-box, the economic value of the fuel would be 8·4735 lbs., showing that whilst the ratio of the surfaces has been increased from 10 to 13, or 30 per cent., there has only been a nominal economy of fuel of from 8·4735 to 8·481, or about 0·09, or rather less than $\frac{1}{10}$ per cent. The actual ratio of the increase of economic effect, as depending upon variations in the

above ratio, or as depending upon any assumed variation of the constant m, is obtainable by the formula in the Appendix. The discussion of this is, however, hardly suitable for the body of the Paper. The result, however, may be briefly stated to be confirmatory of the views before expressed, viz., that neither the length nor the diameter of the tubes, nor the ratio of the tube and fire-box surfaces to each other, or to the fire-grate, are of any practical importance in a locomotive boiler.

Influence of Rate of Combustion as regards Economic Effect of Fuel.

It has been maintained by some authorities that the economic effect of fuel increases with the intensity of the combustion; that is to say, that with an intense heat in the fire-box, the effect of each lb. of fuel is better than with a slow combustion. On the other hand, there are many who maintain exactly the reverse. Referring to Table C, it will be seen that the slow-combustion engines evaporate more water per lb. of fuel than the others. For instance, the first four engines, burning on an average 123 lbs. of coke per hour per square foot of fire-grate, evaporate on an average 7·941 lbs. of water per lb. of coke; whilst the last five engines, averaging 49 lbs. of fuel per square foot per hour, evaporate on an average 9·66 lbs. of water per lb. of coke. This is not, however, due to the rate of combustion, but to the greater relative heating surface, which in the last four engines averaged 1·502 square foot to each lb. of coke, whilst in the first five the average was only 0·524 square foot per lb. of coke. It is moreover evident, from an inspection of the formula, that the rate of combustion has no influence on the economic effect.

The Author now proceeds to examine the question, how far the combustion of fuel in a locomotive boiler is perfect.

It is frequently assumed, that if the air admitted be one-half greater than what is required to supply the oxygen necessary to combine with the carbon and hydrogen in the fuel, perfect combustion will take place; in other words, that if there be this excess of air all the carbon will be converted into carbonic acid, and all the hydrogen into water. In the discussion on Mr. D. K. Clark's Paper, Mr. Robert Stephenson said: "The prevailing opinion was that the combustion of coke was imperfect in the locomotive. He did not now hold that view. He had discussed the subject fully with Professor Daniell, who considered, on the contrary, that the

combustion was most complete."[1] Mr. D. K. Clark, in the Paper, stated that the combustion was practically perfect; and in reply to Mr. C. May, who urged that the gases in the smoke-box should be analysed, said that the proof of the practically complete combustion, founded on the observed evaporative performance of the fuel, was as valid and certain as any that could be derived from a chemical analysis. Now, Mr. Clark's calculation is by no means conclusive. In the first place he assumes a temperature of 600° for the escaping gases. In the next place he assumes 40 cubic feet of air undecomposed to each lb. of coke; and lastly, he attributes 8½ per cent. of the fuel to be ash and water.

In the Memoirs of the Society of Civil Engineers of France, the mean result of actual analysis made by M. de Commines de Marselly, on a passenger engine travelling at 50 miles per hour, is given,[2] and shows that 100 parts of the gases consisted of—

Carbonic acid . . .	12·66	= 3·51 carbon + 9·15 oxygen.
Carbonic oxide . .	7·45	= 3·18 „ + 4·27 „
Air unconsumed . .	5·95	
Nitrogen	73·28	
Unaccounted for . .	0·66	
Total . .	100·00	

In this case, then, 3·18 parts out of 6·69 parts of carbon passed away unconsumed in the shape of carbonic oxide, although the quantity of air was 186 cubic feet per lb. of carbon, or 38 cubic feet in excess of what is theoretically required for perfect combustion. Now the total quantity of carbon in these 100 parts of gases was 6·69, and if the calorific power of carbon be taken at 14,000 units, then the heat generated if all the carbon had been converted into carbonic acid would be 6·69 × 14,000 = 93,660 units; but the actual result was

Carbon into carbonic acid	3·51 × 14,000 =	49,140 units,
„ into carbonic oxide	3·18 × 2,490 =	7,918 „
		57,058 „

or only about 61 per cent. of the actual calorific value of the fuel.

In the mean of other experiments by the same engineer, on a goods engine burning coal, running at the rate of 25 miles per

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xii., p. 415.
[2] *Vide* Mémoires de la Société des Ingénieurs Civils, 1866, p. 616.

hour, the result was 70 per cent. of the carbon reduced to carbonic acid, and 30 per cent. to carbonic oxide. This gives the useful effect as

$$
\begin{aligned}
0\cdot70 \times 14{,}000 &= 9{,}800 \text{ units} \\
0\cdot30 \times \;\, 2{,}490 &= \;\;\; 747 \;\; \text{,,} \\
\hline
&\;\;\; 10{,}547 \;\; \text{,,}
\end{aligned}
$$

out of 14,000 units, or 75 per cent.

The mean of the experiments by M. Foucon, also on a goods engine burning coal, gives 73¾ per cent. of the carbon reduced to carbonic acid, and 26¼ per cent. to carbonic oxide. The useful effect would thus be

$$
\begin{aligned}
0\cdot7375 \times 14{,}000 &= 10{,}325 \text{ units,} \\
0\cdot2625 \times \;\, 2{,}490 &= \;\;\;\; 654 \;\; \text{,,} \\
\hline
&\;\;\; 10{,}979 \;\; \text{,,}
\end{aligned}
$$

or 78 per cent.

It is apparent from these experiments, which were on an extensive scale, and made with great care, that there was a loss of fuel by imperfect combustion varying from 39 to 22 per cent.

A result corroborative of this was arrived at from the experiments made in 1857 and 1858, on a marine tubular boiler, by Sir W. G. Armstrong, C.B., M. Inst. C.E., Dr. Richardson, and the Author. It was then proved that, by a due admission of air above the fuel in the fire-grate, the evaporative power of the fuel was increased from 17 to 22 per cent.

An examination of Table A still further corroborates this view. Taking, for instance, the Caledonian engine No. 51, burning 55 lbs. of coke per square foot of fire-grate per hour, it is found that it actually evaporated 0·1453 cubic foot per lb. of fuel, as against 0·1540, the quantity due to the formula; whilst No. 13, an engine almost identical in dimensions, but burning 108 lbs. per square foot of grate, only evaporated 0·1076 cubic foot, as against the formula quantity of 0·1350. The deficiency below the formula is 5·85 per cent. in the former case, and 20·3 per cent. in the latter. This evidently points to imperfect combustion, arising, no doubt, from the large amount of fuel burnt per square foot, and the deficiency of air admitted into the box.

Upon a review of the whole case, it appears that, under certain conditions, the combustion of the fuel is approximately perfect; whilst in others a considerable amount is loss in the shape of carbonic oxide escaping unconsumed.

The general conclusions arrived at from the preceding investigation may be summed up as follows:—

1st. That no fixed rule can be established as the best for the relative proportions of fire-grate, fire-box, and tube surfaces.

2nd. That length of tube has nothing to do with economic effect.

3rd. That the diameter of the tube is also a matter of indifference.

4th. That the economy of fuel does not depend upon the rate of firing.

5th. That when the quantity of fuel burnt is moderate, say 50 or 60 lbs. per square foot of grate per hour, the combustion is nearly perfect. On the other hand, with hard firing a considerable loss results from carbonic oxide passing away unconsumed.

6th. That a large increase of heating surface in proportion to coal burnt only slightly increases the economical effect. In fact, within the limits of practice in locomotive engines, the economic effect is in proportion to about the fourth root of the heating surface.

There are other questions of great interest connected with the evaporation from locomotive boilers which for the present the Author must leave untouched, the most important being the action of the blast pipe, or other means of increasing the combustion of fuel per square foot of grate, and that of the admission of air otherwise than through the grate bars.

The object of the present Paper was to analyse the action of the various portions of the boiler, and to clear away misconceptions regarding the same, rather than to attempt anything like a treatise on Boiler Construction. The Author hopes he has not altogether failed in establishing the principles which should guide constructors on a rational basis, and in putting them into the shape of formula which have a real practical value.

This Paper is accompanied by diagrams, from which Figs. 1 and 2 have been engraved.

APPENDIX.

I.

INVESTIGATION OF THE EVAPORATIVE POWER OF FIRE-BOX SURFACE.

Let U = units of heat utilisable arising from the combustion of 1 lb. of fuel.
w = weight of gases and unconsumed air arising from the combustion of 1 lb. of fuel.
σ = specific heat of this mixture.
S = surface of fire-box in square feet.
s = surface of tubes (exterior) in square feet.
G = surface of fire-grate in square feet.
W = lbs. of fuel consumed per hour per square foot of fire-grate.
N = units of heat required to evaporate 1 cubic foot of water from 60° into steam at the temperature of the water in boiler.
T = temperature of water in boiler.
θ = temperature of the gases at their exit from the tubes.
x = temperature of gases in the fire-box before entering the tubes above the temperature of the water.
m = units of heat transmitted per hour through 1 square foot of surface for each degree of Fahr. of difference of temperature.

Then $U W G$ = total heat generated per hour.
$S m x$ = heat transmitted through the surface of the fire-box into the water per hour.
$W G w$ = weight of products of combustion and unconsumed air developed per hour.
$W G w \sigma (x + T)$ units of heat taken up by $W G w$.

therefore $$U W G = S m x + W G w \sigma (x + T),$$

whence $$x = \frac{W G (U - T w \sigma)}{S m + W G w \sigma} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

which is the excess of the temperature of the gases in the fire-box above the temperature of the water outside. Since N denotes the units of heat required to evaporate 1 cubic foot of water from 60° Fahr. = 70,000 units,[1]

the water evaporated from the fire-box $= \dfrac{S m x}{N}$ . . . . (2)

[1] More accurately this is 71,750 units, with which value the figures in column 3, Table B, have been calculated, whilst those in Table A were calculated with N = 70,000 units.

II.

Evaporation from the Tube Surface.

Let τ = temperature of the gases entering the tubes
$= x + \mathrm{T}$.
Q = weight of gases passing through the tubes per hour
$= \mathrm{W\,G}\,w$.
d = external diameter of tubes.
n = number of tubes.
l = length of tubes.
η = any variable distance along the tubes reckoned from the fire-box end.
θ' = temperature of the gases at η.

Then if $\delta\,\theta$ = loss of temperature in passing through $\delta\,\eta$.
$\mathrm{Q}\,\sigma\,\delta\,\theta'$ = loss of heat of gases in passing through $\delta\,\eta$,

which must be equal to the quantity transmitted to the water;

but this is $= n\,\pi\,d\,m\,(\theta' - \mathrm{T})\,\delta\,\eta$ and since $\delta\,\theta$ is negative

$$-\,\delta\,\theta' = \frac{n\,\pi\,d\,m}{\mathrm{Q}\,\sigma}\,(\theta' - \mathrm{T})\,\delta\,\eta$$

$$= \frac{n\,\pi\,d\,m}{\mathrm{W\,G}\,w\,\sigma}\,(\theta' - \mathrm{T})\,\delta\,\eta$$

and writing A for $\frac{n\,\pi\,d\,m}{\mathrm{W\,G}\,w\,\sigma}$, $\delta\,\theta' = \mathrm{A}\,\theta'\,\delta\,\eta - \mathrm{A\,T}\,\delta\,\eta$.

Multiplying both sides by $\epsilon^{\mathrm{A}\,\eta}$, where ϵ is the base of the hyp. logarithm = 2·718

$$\mathrm{A}\,\theta'\,\epsilon^{\mathrm{A}\,\eta}\,\delta\,\eta + \epsilon^{\mathrm{A}\,\eta}\,\delta\,\theta' = \epsilon^{\mathrm{A}\,\eta}\,\mathrm{A\,T}\,\delta\,\eta\,;$$

whence integrating $\theta'\,\epsilon^{\mathrm{A}\,\eta} = \mathrm{T}\,\epsilon^{\mathrm{A}\,\eta} + \text{constant}$;

but when $\eta = 0$ $\theta' = \tau$, therefore $\tau = \mathrm{T} + \text{constant}$, and the constant $= \tau - \mathrm{T}$.

Hence $\theta'\,\epsilon^{\mathrm{A}\,\eta} = \mathrm{T}\,\epsilon^{\mathrm{A}\,\eta} + \tau - \mathrm{T} = \tau + \mathrm{T}\,(\epsilon^{\mathrm{A}\,\eta} - 1)$; but $\tau = \mathrm{T} + x$,

therefore
$$\theta' = \mathrm{T} + \frac{x}{\epsilon^{\mathrm{A}\,\eta}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

which is the temperature of the gases at any point η along the tubes; and making $\eta = l$ the length of the tubes, $\theta' = \mathrm{T} + \frac{x}{\epsilon^{\mathrm{A}\,l}}$, and substituting for A its value $\frac{n\,\pi\,d\,m}{\mathrm{W\,G}\,w\,\sigma}$, and writing S′ for $n\,\pi\,d\,l$, which is the total heating surface of the tubes,

then
$$\theta' = \mathrm{T} + \frac{x}{\epsilon^{\frac{m\,\mathrm{S}'}{\mathrm{W\,G}\,w\,\sigma}}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

and denoting by h the quantity $\mathrm{W\,G}\,w\,\sigma$, then

$$\theta' = \mathrm{T} + \frac{x}{\epsilon^{\frac{m\,\mathrm{S}'}{h}}}$$ the temperature at the exit from the

tubes; but $T + x$ was the temperature at the entrance, therefore the reduction of temperature by the tubes is

$$= T + x - T + \frac{x}{\epsilon^{\frac{ms}{h}}}$$

$$= x\left\{1 - \frac{1}{\epsilon^{\frac{ms}{h}}}\right\}$$

and the heat given out $= h\,x\left\{1 - \frac{1}{\epsilon^{\frac{ms}{h}}}\right\}$.

Consequently the water evaporated by the tubes is

$$= \frac{h\,x}{N}\left\{1 - \frac{1}{\epsilon^{\frac{ms}{h}}}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

III.

Total Evaporation of Boiler.

Evaporation from fire-box $= \frac{S\,m\,x}{N}$ . . . . (6)

Evaporation from tubes $= \frac{h\,x}{N}\left\{1 - \frac{1}{\epsilon^{\frac{ms}{h}}}\right\}$ . . . . (7)

Total evaporation from boiler $= \frac{x}{N}\left\{S\,m + h\left(1 - \frac{1}{\epsilon^{\frac{ms}{h}}}\right)\right\}$ . . . (8)

in which equations $x = \frac{W\,G\,(U - T\,w\,\sigma)}{S\,m + W\,G\,w\,\sigma}$

and $h = W\,G\,w\,\sigma$

$\epsilon = 2{\cdot}718.$

IV.

Economic Effect of 1 lb. of Fuel.

The preceding formulæ give the cubic feet of water evaporated per hour by any locomotive boiler of which the dimensions and the consumption of fuel per hour are known.

From them may be derived an expression showing the economic value of 1 lb.

of fuel in a boiler of given dimensions, for taking equation (8), the total evaporation from the boiler per hour with a consumption of W G lbs. of fuel

$$= \frac{x}{N}\left\{S m + h\left(1 - \frac{1}{\epsilon^{\frac{s m}{h}}}\right)\right\};$$

and substituting for x its value from equation (1), and for h its value $= W G w \sigma$, the total evaporation in cubic feet per hour with a consumption of W G lbs. of fuel

$$= \frac{W G (U - T w \sigma)}{N(S m + W G w \sigma)}\left\{S m + W G w \sigma\left(1 - \frac{1}{\epsilon^{\frac{s m}{W G w \sigma}}}\right)\right\}$$

and dividing by W G, and writing P for $(U - T w \sigma)$,

η = evaporation in lbs. from 1 lb. of fuel per hour

$$= 62 \cdot 5 \frac{P}{N} \cdot \frac{S m + W G w \sigma\left(1 - \frac{1}{\epsilon^{\frac{s m}{W G w \sigma}}}\right)}{S m + W G w \sigma}$$

and making the consumption of fuel W G = 1 lb. per hour, then

$$\eta = 62 \cdot 5 \frac{P}{N} \cdot \frac{S m + w \sigma\left(1 - \frac{1}{\epsilon^{\frac{s m}{w \sigma}}}\right)}{S m + w \sigma}$$

$$= 62 \cdot 5 \frac{P}{N} \cdot \frac{S m + w \sigma - w \sigma \epsilon^{-\frac{s m}{w \sigma}}}{S m + w \sigma}$$

$$= 62 \cdot 5 \frac{P}{N} \cdot \left\{1 - \frac{w \sigma \epsilon^{-\frac{s m}{w \sigma}}}{S m + w \sigma}\right\}$$

assume $v = S + s$ = total heating surface

and $S = \frac{s}{n}$

then $S = \frac{v}{n+1}$ and $s = \frac{n}{n+1} v$

$$\eta = 62 \cdot 5 \frac{P}{N} \cdot \left\{1 - \frac{w \sigma \epsilon^{-\frac{n}{n+1}\frac{m}{w \sigma} v}}{\frac{m}{n+1} v + w \sigma}\right\} \quad . \quad . \quad . \quad . \quad . \quad (9)$$

By this formula the relation between the heating surface per lb. of fuel and the evaporative effect may be accurately determined.

Substituting, for the various constants, the values already used this becomes

$$\eta = 62 \cdot 5 \times \frac{11{,}000}{70{,}000}\left\{1 - \frac{4 \cdot 033\, \epsilon^{-2 \cdot 727\, v\, \frac{n}{n+1}}}{\frac{11 v}{n+1} + 4 \cdot 033}\right\}$$

$$= 9 \cdot 82\left\{1 - \frac{0 \cdot 3666 (n+1)}{v + \cdot 3666 (n+1)} \times \frac{1}{\epsilon^{2 \cdot 727\, v\, \frac{n}{n+1}}}\right\}$$

and applying this to the "Sphinx" where

$$v = 0 \cdot 734 \quad n = 12 \cdot 98,$$

then $$\eta = 9 \cdot 821 \left\{ 1 - \frac{\cdot 36664 \times 13 \cdot 98}{(\cdot 734 + \cdot 3666 \times 13 \cdot 98) \times 2 \cdot 718^{2 \cdot 727 \times \cdot 734 \times \frac{12 \cdot 98}{13 \cdot 98}}} \right\}$$

which gives $$\eta = 8 \cdot 481,$$

or the same value as is found in the Table as the evaporative effect of 1 lb. of fuel.

If now in the same engine the amount of heating surface be preserved, but the ratio of the tube to the fire-box surface be made 10 to 1, then

$$\eta = 9 \cdot 821 \left\{ 1 - \frac{\cdot 36664 \times 11}{(\cdot 734 + 36{,}664 \times 11) \times 2 \cdot 718^{2 \cdot 727 \times \cdot 734 \times \frac{10}{11}}} \right\}$$

from which $$\eta = 8 \cdot 4735,$$

showing that the effect of increasing the ratio of the tubes to the fire-box from 10 to 12·98, or about 30 per cent., has only increased the economic value of the fuel from 8·4735 to 8·481, or ·0075 of a pound.

V.

Effect of varying the ratio n of Tube to Fire-box Surface on Economic Value of Fuel.

Another question of interest is to determine the effect on the economic value of 1 lb. of fuel of varying the ratio n, and what is the best value for this ratio. It is evident that the fraction which forms the second term of the expression within the brackets in equation (9) decreases as n increases, consequently the value of η increases as n increases; that is to say, the most economical results would be attained if the whole heating surface consisted of tube surface.

It may, however, be shown that the ratio of increase of η, that is, of the economic effect, is small compared with the increase of the ratio of the tube to the fire-box surface. For this purpose, taking equation (9), and making v constant and n variable, and taking the differential co-efficient $\frac{\delta \eta}{\delta n}$, an expression is obtained denoting the ratios of these increments :—

$$\frac{\delta \eta}{\delta n} = 62 \cdot 5 \, \frac{P}{N} v^2 \left\{ \frac{m^2}{w \sigma \epsilon^{\frac{m v}{w \sigma} \cdot \frac{n}{n+1}} \times (n+1) \{v m + w \sigma (n+1)\}} \right\} \quad (10)$$

For example the "Sphinx" would have the following values :—

$$v = 0 \cdot 734 \qquad w \sigma = 4 \cdot 033$$
$$P = 11{,}000 \qquad n = 12 \cdot 98$$
$$N = 70{,}000 \qquad m = 11$$

Hence $$\frac{\delta \eta}{\delta n} = 62 \cdot 5 \times \frac{11{,}000}{70{,}000} \times \cdot 734^2 \times$$

$$\left\{ \frac{11^2}{4{,}033 \times 2 \cdot 718^{1 \cdot 8584} \times 13 \cdot 98 \{8 \cdot 074 \times 4 \cdot 033 \times 13 \cdot 98\}} \right\} = \cdot 002747,$$

showing the slight influence of varying the ratio between the box and tube surface.

VI.

On the Relative Variation of the Evaporative Power and the Transmissive Capacity (m) of the Heating Surface.

Let E be the evaporative power of the boiler,

then
$$E = \frac{S\,m\,x}{N} + \frac{h}{N}\,x\left\{1 - \frac{1}{\epsilon^{\frac{s}{h}m}}\right\}$$

and replacing x by its value $\dfrac{W\,G\,(U - T\,w\,\sigma)}{S\,m + W\,G\,w\,\sigma}$

and writing A for $W\;G\;(U - T\,w\,\sigma)$
B for $W\;G\,w\,\sigma$ or h

then
$$E = \frac{A}{N}\left\{1 - \frac{B}{(S\,m + B)\,\epsilon^{\frac{s}{B}m}}\right\}.$$

whence taking the differential co-efficient

$$\frac{\delta E}{\delta m} = \frac{A}{N}\left\{\frac{S\,s\,m + B\,(S + s)}{(S\,m + B)^2\,\epsilon^{\frac{s}{B}m}}\right\} \quad . \quad . \quad . \quad . \quad (11)$$

Taking, again, the case of the "Sphinx," substituting the values and making $m = 11$, then

$$\frac{\delta E}{\delta m} = \frac{1658 + 11000}{70000} \times \frac{86\cdot7 + 1126 \times 11 + 6687 \times 1212\cdot7}{(953\cdot7 + 6687)^2 \times 6\cdot36} = 6\cdot44.$$

The result of this is that if m be increased by 1 the evaporative power will be increased by 6·44 cubic feet per hour. This ratio depends, however, upon the value of m; for instance, if m instead of 11 had been 22, and be then increased to 23, the increase in the evaporative power would have been only 4·75 cubic feet per hour, and in like manner for higher values of m.

In the case of the "Sphinx" it may be said that the value of $m = 12$, giving the evaporation 231 cubic feet per hour, agrees better with the actual result of 233 cubic feet than the former value. This is quite true as regards the "Sphinx," but in applying the increased value to other engines it is found that the evaporation works out too high, and, moreover, the value of $m = 11$ agrees best with the recorded experiments in the Paper. Upon a full consideration of the case the Author is at present disposed to fix upon $m = 11$ as nearest to the true value. It is, however, desirable that further experiments should be made so as to ascertain the true value.

VII.

To find w the Weight of the Products of Combustion from 1 lb. of Fuel.

Carbonic acid = (75 carbon + 200 oxygen)

	lbs.
requires oxygen $0 \cdot 90 \times \frac{200}{75} =$	2·40 oxyge·
add carbon	0·90
	3·30

but since air = 350 nitrogen + 100 oxygen, the air required for 2·40 lbs. oxygen = 10·8 lbs., and this liberates

Nitrogen	8·40
to which must be added	
Water in fuel	0·05
Air in excess unconsumed, say ⅓ of total quantity .	5·40
	17·15

or say 17 lbs. of gases from each lb. of coke,

therefore $w = 17$ lbs.

VIII.

To find σ the Specific Heat of the Escaping Gases.

Carbonic acid . . .	3·30 × 0·216 =	0·7128
Nitrogen	8·40 × 0·244 =	2·0496
Water (steam) . . .	0·05 × 0·475 =	0·0237
Air	5·40 × 0·237 =	1·2798
	17·15	4·0659

$$\text{therefore the mean specific heat} = \frac{4 \cdot 0659}{17 \cdot 15} = 0 \cdot 237$$

or $\sigma = 0 \cdot 237$.

IX.

Introduction of Numerical Values of Constants into Formulæ (6), (7), (8).

Substituting these values in the formula (1), then

$$x=\frac{W\,G\,(12{,}390-T\,(17\times\cdot237))}{11\,S+W\,G\,(17\times\cdot237)}$$

and if T be 347°, which corresponds to a pressure of about 115 lbs. above the atmosphere,

then $$x=\frac{W\,G\times11{,}000}{11\,S+W\,G\times4\cdot033}$$

which is the temperature in the fire-box. Substituting this value in equation (2),

then the evaporation from the fire-box $=\dfrac{11\,S\times11{,}000\,W\,G}{70{,}000\,(11\,S+4\cdot033\,W\,G)}$.[1]

And if for W G, the hourly consumption of fuel, be written F, and the expression be reduced, it will be found that the

$$\text{Evaporation from the fire-box}=\frac{1\cdot73\,S\,F}{11\,S+4\cdot033\,F}\quad.\ .\ .\ .\ .\ .\ .\ (6)$$

$$\text{Evaporation from tubes}=\frac{0\cdot634\,F^2\left\{1-\dfrac{1}{\epsilon^{2\cdot727\frac{s}{F}}}\right\}}{11\,S+4\cdot033\,F}\quad.\ .\ .\ .\ (7)$$

$$\left.\begin{array}{l}\text{Total evaporation of boiler in}\\ \text{cubic feet per hour}\end{array}\right\}=\frac{1\cdot73\,S\,F+\cdot634\,F^2\left\{1-\dfrac{1}{\epsilon^{2\cdot727\frac{s}{F}}}\right\}}{11\,S+4\cdot033\,F}\quad.\ (8)$$

in which

S = heating surface of fire-box in square feet.
s = „ „ of tubes „ „
F = lbs. of fuel (coke) burnt per hour.
$\epsilon = 2\cdot718$.

X.

Examination of Mr. Zerah Colburn's Theory that the Evaporative Effect per square foot of Tube Surface varies inversely as the Square of the Diameter.

Let w = the weight of gases passing per unit of time,
τ = the temperature,
σ = the specific heat,
d = the diameter of the tube,
l = any length of tube.

Then the heat radiated to the surface for the length l is proportional to $\dfrac{w\,\tau\,\sigma}{d^2}$ and also to the surface $\pi\,d\,l$. It is also proportional to the time the gases are in

---

[1] More accurately, if the water be evaporated from 60°, N = 71,750 units.

contact in passing through l. Denoting by H, the heat radiated per hour, it will be found $H = C \frac{w \tau \sigma \pi d l t}{d^2}$, C being a constant; but if v be the velocity of the gases, $l = v t$, and if A be the co-efficient of the volume of the gases, the volume $= w A$, consequently $v = \frac{A w}{\frac{1}{4} \pi d^2}$ and $t = \frac{l}{v} = \frac{l \pi d^2}{4 A w}$; and substituting this in the equation for H, then $H = \frac{C}{4 A} \tau \sigma \pi^2 l^2 d$, and taking l for unity of length $H = \frac{C}{4 A} \tau \sigma \pi^2 d$; that is to say, the heat radiated is directly as the diameter, but the absorbing surface is also directly as the diameter, therefore the heat radiated per unit of surface is independent of the diameter of the tube.

XI.

Application of the Formula to determine the Dimensions of a Boiler which shall Evaporate a given Quantity of Water with a given Economic Rate of Evaporation.

Let it be required to evaporate 300 cubic feet of water per hour with a consumption of coke of 1 lb. for each 9 lbs. of water.

Then the consumption of fuel per hour $= \frac{300 + 62 \cdot 5}{9} = 2,083$ lbs. of coke.

The value of v, equation (9), must now be determined. Make $\eta = 9$, and adopt any value for n that is most convenient, since it has been shown that a variation in the value of n makes little difference in η. Let $n = 12$, then

$$9 = 62 \cdot 5 \frac{11,000}{70,000} \left\{ 1 - \frac{4 \cdot 033}{\left(\frac{11}{13} \cdot v + 4 \cdot 033 \right) \epsilon^{\frac{12}{13} \cdot \frac{11}{4 \cdot 033} v}} \right\},[1]$$

$$= 9 \cdot 82 \left\{ 1 - \frac{4 \cdot 766}{(v + 4 \cdot 766)\, 12 \cdot 4^{v}} \right\}$$

from which $v = \cdot 914$.

Consequently the total heating surface

$$= 2,083 \times \cdot 914 = 1,904 \text{ square feet;}$$

and since $n = 12$,

heating surface of tubes $= 1,904 \times \frac{12}{13} = 1,757$ square feet;

" " fire-box $= 1,904 \times \frac{1}{13} = \frac{147}{1,904}$ " "

which is the heating surface required.

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[1] If the water be evaporated from 60°, the value of N in the denominator must be taken as 71,750, instead of 70,000.

XII.

To show the Reduction of Temperature in passing along a Tube.

Take the case of the "Sphinx," burning 157 lbs. of coke per square foot of fire-grate. From the formula it is found that the temperature in the fire-box is $x = 2{,}387^\circ$ above the water, and the temperature at any point η along the tube is $\theta = \mathrm{T} + \dfrac{x}{\epsilon^{\frac{n \pi d m}{\mathrm{W}\,\mathrm{G}\,w}\eta}}$ from which the following values are obtained, making $\eta = 1, 2, 3$, &c., up to 20 feet from the fire-box end.

η	θ	θ
	°	
1	347 + 2,096 =	2,443
2	347 + 1,841 =	2,188
3	347 + 1,616 =	1,963
4	347 + 1,419 =	1,766
5	347 + 1,246 =	1,593
6	347 + 1,094 =	1,441
7	347 + 961 =	1,308
8	347 + 844 =	1,191
9	347 + 741 =	1,088
10	347 + 651 =	998
11	347 + 571 =	918
12	347 + 502 =	849
13	347 + 440 =	787
14	347 + 378 =	725
15	347 + 332 =	679
16	347 + 291 =	638
18	347 + 225 =	572
20	347 + 173 =	520

Which values are shown by the curved lines in Fig. 1, p. 111.

[Addendum.

ADDENDUM.

No. 1,534A.—"On the Action of the Blast-pipe on Locomotive Engines." By JAMES ATKINSON LONGRIDGE, M. Inst. C.E.

Although it is much the fashion with writers on the locomotive engine to attribute its great success to the action of the blast pipe, such a notion has only a limited basis as a matter of fact. The blast-pipe, though a powerful agent in effecting rapid combustion, is *per se* a very extravagant one; and it is only from the circumstance that in the locomotive engine there is a large amount of steam which, escaping from the cylinders, is available for the purpose, and which otherwise would be wasted, that the blast-pipe has maintained its reputation as an instrument for creating a draught.

As is well known, the "Novelty" constructed by Mr. Ericsson, and which excited so much admiration at the trials at Rainhill in the year 1829, was not dependent on the blast-pipe, the air for combustion being supplied by a bellows.

Although the power required to supply the proper quantity of air in a locomotive engine is but small, yet it is obvious that so long as that power can be obtained from the action of the escaping steam which would otherwise be lost, it would be a waste to employ even that small amount of power in the supply of air. There are, however, circumstances under which the substitution of a blower for the blast-pipe may prove advantageous. For instance, in South America where the water is so saturated with saline matter as to be utterly unfit for use, and where every drop of water has to be distilled, condensed, and then transported many miles for the supply of the locomotive engines; so that the cost of water sometimes exceeds the cost of fuel. In such cases, the adoption of surface condensation would be a great boon, and then the air would have to be supplied by a blower. The surface condensation would, of course, have to be obtained from contact with the external air instead of water; and though the Author is not at present prepared to bring forward any complete system by which this could be accomplished, he may state, as the result of his investigation, that the problem is one that admits of a practical solution. The quantity of air required to be brought in contact with the condensing surface, and the condensing surface itself would be large, and would vary with the climate in which

the system had to work, but both are within practical limits, and the system could, no doubt, be applied with advantage under certain circumstances. Before leaving this question the Author feels it right to say, that the system of surface condensation by air was many years ago advocated and actually applied in practice by Mr. Thomas Craddock, a gentleman whose ingenuity and perseverance has, unfortunately for him, met with the too common reward of heavy pecuniary loss.

Returning to the subject of the blast-pipe, the Author thinks a brief account of some results which he has obtained regarding its action may be acceptable.

About the year 1849 the steam jet, as a motive power for the ventilation of coal mines, attracted much attention, and was held up by some authorities, and especially by Mr. Goldsworthy Gurney, as by far the most efficient and economical application of power for moving large bodies of air, and its application to the locomotive was instanced as a proof of its vast efficiency.

The Author at that time undertook an extensive series of experiments, in order to ascertain as far as he could its laws of action; and in the year 1852 he read a paper on the subject before the North of England Institute of Mining Engineers.[1]

Although these experiments were numerous they were not sufficient to exhaust the subject, but the following results were arrived at:—

1. That the action of a jet of steam was not an impulsive action as maintained by Mr. Gurney, but was the result of a frictional action between the surface of the jet of steam and the surrounding air.

2. That a greatly increased action was obtained by subdividing the jets. This follows as a corollary from the preceding remark. The quantity of steam expended varying as the square of the diameter of the jet, whilst the surface exposed varies as the diameter simply and the effect varying as the surface, it is evident that with a given exhaustion of steam the efficiency is increased with the number of jets, i.e., as their diameter is decreased.

3. That lengthening the chimney increases the effect of the jet until the length is about eight times the diameter, after which it begins to decrease. The increase is, however, very slow after about four times the diameter.

4. That with the same blast-pipe and chimney the effect, as

[1] *Vide* Transactions, vol. i., p. 165.

measured by the vacuum produced, is inversely as the square of the diameter of the chimney.

5. That the effect is about as the 0·8 power of the pressure of the issuing steam measured in pounds per square inch above the atmospheric pressure.

From the Author's experiments, which were made with various sizes of jet and chimney, and with pressures ranging from 5 lbs. to 60 lbs. per square inch, he was enabled to deduce the following expression for the exhaustive power of a jet of steam:—

$$E = 37 \frac{d^{1 \cdot 662}}{D^2} p^{0 \cdot 8},$$

when E = exhaustive power in inches of water.
d = diameter of jet or blast-pipe in inches.
D = diameter of chimney in inches.
p = pressure of steam in lbs. per square inch above the atmosphere.

The above formula was found to agree closely with the results obtained by the late Mr. Nicholas Wood in the experiments made by him in 1853 in various collieries in the north of England.[1] The Author has recently applied the same formula to locomotive engines, by calculating the amount of exhaustion in the smoke-box of two or three engines, of which the details are given in Mr. D. K. Clark's treatise on Railway Machinery, p. 128, with the following results:—

CALEDONIAN ENGINE, No. 25.

	Blast Pressure.		Effect as Measured by Exhaustion in Smoke-box in Inches of Water.	
	Inches of Mercury.	Lbs. per Square Inch.	By Formula.	By Experiment.
37 miles per hour.	2	1·111	1·819	1·75
	2½	1·39	2·176	2·25
	2¾	1·53	2·350	2·50
	3½	1·944	2·843	3·00
	4½	2·50	3·480	3·50
	5	2·78	3·788	3·75
	5½	3·05	4·075	4·00
	5¾	3·19	4·229	4·125
35 miles per hour.	3	1·66	2·51	2·78
	5	2·77	3·77	3·75
	6½	3·50	4·56	4·50
	8¼	4·73	5·79	5·50

[1] *Vide* North of England Institute of Mining Engineers. Transactions, vol. i., p. 71 *et seq.*

In the experiments made by Mr. Nicholas Wood in coal mines, the pressure of steam varied from 20 lbs. to 40 lbs. per square inch above the atmosphere. The jets were of small diameter, varying from $\frac{3}{16}$ to $\frac{7}{8}$ diameter, and in number from thirty to sixty.

The results of calculations from the above formula accord very well with the observed results, and with the tables just given for the Caledonian Engine, No. 25.

It may therefore, perhaps, be assumed that the formula, though empirical, represents with tolerable accuracy the exhaustive power of the jet or blast-pipe.

The Author has calculated by this formula the effect produced by the blast-pipe in eight of the engines mentioned in Table A.

The method of procedure was as follows:—

1. From the water actually evaporated, and the area of the blast pipe, the pressure of the issuing steam may be obtained from the formula:—

$$P = \sqrt{\frac{C^2}{1 \cdot 526\, d^4} + 9 \cdot 5^2} - 9 \cdot 5\,;$$

when P = pressure of steam above the atmosphere in lbs. per square inch.
C = cubic feet of water evaporated per hour.
d = diameter of blast-pipe in inches.

2. From this pressure the vacuum in the smoke-box is obtained from the formula—

$$W\,G = 37 \times \frac{d^{1 \cdot 662}}{D^2} \times P^{\cdot 8}\,;$$

when W G = vacuum as measured by the water-gauge in inches.
d = diameter of blast-pipe in inches.
D = diameter of chimney in inches.
P = pressure of steam in lbs. per square inch above the atmosphere.

The latter is then divided into two parts, one of which is required to overcome the resistance of the fire-grate and tubes, and the other to give the velocity of the gases through the chimney.

The following table, D, gives the results :—

TABLE D.

Name of Engine.	Area of Fire-grate.	Diameter of Chimney.	Diameter of Blast-pipes.	Lbs. of Coke per Square Foot of Grate per Hour.	Cubic Feet of Water Evaporated per Hour.	Pressure of Blast in lbs. per Square Inch.	Vacuum in Smoke-box in Inches of Water.	Resistance of Chimney in Inches of Water.	Resistance of Grate and Tubing in Inches of Water.
	Sq. feet.	Inches.	Inches.						
"Snake". .	12·40	13	$4\frac{1}{4}$	75	152	2·70	5·368	2·861	2·507
"Sphinx" .	10·56	$15\frac{1}{2}$	$4\frac{3}{4}$	157	233	3·25	6·234	3·760	2·474
No. 51 . .	10·5	15	4	55	84	0·89	1·500	0·383	1·117
" 33 . .	10·5	15	4	42	71	0·61	1·111	0·213	0·898
" 13 . .	10·5	$14\frac{3}{8}$	$4\frac{3}{32}$	108	122	1·67	2·816	2·330	0·484
" 124 . .	11·37	$17\frac{1}{2}$	$3\frac{9}{16}$	66	99	1·97	1·362	0·552	0·810
" 102 . .	11·8	14	$4\frac{1}{16}$	93	120	1·68	2·904	1·340	1·564
"Pallas". .	16·04	15	$4\frac{5}{8}$	38	97	0·68	1·540	0·602	0·938

The actual power expended by the blast-pipe will now compared with the effect produced.

The object of the blast-pipe being to force air through the fire-grate, fuel, and tubes, it is obvious that this only can be considered as useful effect. All the power employed in forcing the gases through the chimney is of the nature of a resistance inherent in the action of the machine or apparatus, and consequently cannot be considered as useful effect.

The method of procedure here is to calculate the work done from the well-known formula—

$$\text{Work done} = \frac{W\,V^2}{2g};$$

when W = weight of steam passing per second.
V = velocity of steam passing in feet per second.
$g = 32{\cdot}2$.

This, divided by 550, gives the HP. expended.

Again, taking the amount of vacuum in the smoke-box in lbs. per square inch, multiplied by the area of the chimney and by the velocity of the gases, the work done in forcing the gases through the chimney is found, which again, divided by 550, gives the HP. Subtracting this from the former result, the HP. expended in

forcing the air through the grate, the fuel, and the tubes (which represents the useful effect), is obtained.

These have been calculated for three engines, the "Snake," the "Sphinx," and the Caledonian, No. 51. In the "Snake" evaporating 152 cubic feet of water per hour, the velocity of the steam escaping through the blast-pipe at a pressure of 2·70 lbs. per square inch, is 656 feet per second. This represents an expenditure of about 32 HP. Taking the vacuum in the smoke box at 5·368 inches of water, this gives a useful effect of $6\frac{4}{10}$ HP. thus applied:—

	HP.
To give velocity to the gases through the chimney .	3·4
To increase the resistance of the tubes and fire grate	3·0

The latter only being taken as the power to supply the air, the useful effect is found to be little more than one-eleventh of the power expended = 9 per cent.

In like manner with the "Sphinx" evaporating 233 cubic feet of water per hour, the total power expended by the blast jets was 67·8 HP. thus applied:—

	HP.
To give velocity through the chimney	8·03
Resistance of grate and tubes	5·77
Loss	54·00
	67·80

So that the actual power to supply the air, or the useful effect, was only $\frac{1}{11\cdot 8}$ of the whole = $8\frac{1}{2}$ per cent.

Lastly, with a slow combustion engine, No. 51 Caledonian, evaporating 84 cubic feet per hour and burning 55 lbs. of coal per square foot of coals, the total power expended by the blast-pipe is 8·04, thus applied:—

	HP.
To give velocity to the gases through the chimney	0·221
For resistance of grate and tubes	0·639
Loss	7·180
	8·040

And the actual power to supply the air was only $\frac{1}{12\cdot 8}$ of the whole = 7·8 per cent.

Table E represents the results of these calculations, the total HP. of the engines being calculated at 2¼ HP. for each cubic foot of water evaporated per hour :—

TABLE E.

1 Name of Engine.	2 Total HP.	3 HP. Expended by Blast-pipe.	4 HP. for Resistance of Chimney.	5 HP. for Resistance of Grate and Tubes.	6 Ratio of Column 5 to Column 3.
					Per cent.
"Snake" . . .	317	32·00	3·400	3·000	9·0
"Sphinx" . . .	524	67·80	8·030	5·770	8·5
No. 51	189	8·04	0·221	0·639	7·8

The average of these three cases shows that the actual power required to force the air through the grates and tubes, exclusive of the chimney, was about 8½ per cent. of the power expended, from which it follows that the blast-pipe, considered as a motive power and as applied in the locomotive engine, is a very wasteful apparatus.

But it may be said that this is a matter of small consequence, inasmuch as the exhaust steam if not so applied would be absolutely wasted. To a great extent this is true, putting aside for the present the case of condensing locomotives. But though this large amount of power is available, there are circumstances under which the present method of application is, in the Author's opinion, very imperfect. It happens not unfrequently that at the time when the demand for steam is the greatest the power of the blast-pipe falls off. This power is evidently governed by the supply of steam, and, on the other hand, the supply of steam is governed by the power of the blast-pipe.

Now, in all the previous reasonings it has been supposed that the blast-pipe acts as a continuous jet, and this is approximately the case whilst the speed of the engine is considerable. But when the speed is reduced and the pressure in the cylinder increased, as happens on ascending a gradient, the action of the blast-pipe becomes intermittent; it is, in fact, a series of impulses each involving a considerable loss of *vis viva*. The effect, therefore, of each cubic foot of water passing through the blast-pipe is reduced, and hence the evaporation of the boiler falls off; this again reacts on the blast-pipe, and hence at the time when active combustion is most required, it dies away. The question, therefore is, whether, with

so large an excess of available power, it may not be practicable so to apply it that there may be no deficiency under such circumstances as those just referred to.

In the Author's opinion this may be done effectually by subdividing the escaping steam into a number of jets, each furnished (though not necessarily so) with its own chimney. The effect of this will be best shown by an example. Taking the Caledonian engine, No. 51, evaporating 84 cubic feet of water per hour:

The blast-pipe of this engine is . . .	4 inches diameter.
The chimney	15 ,, ,,
The pressure of the escaping steam .	0·89 lb. per sq. inch.
The vacuum in the smoke-box . . .	1·50 inch of water.

Now if the same area of blast-pipe be substituted in jets of ½-inch diameter, this would give sixty-four jets; and if each jet worked into a chimney of 1⅞ inch diameter, this would give the chimney an area of 176·7 inches—the same as before.

By the application of the same formula the vacuum in the smoke-box would be found to be 3·029 inches of water, or rather more than double what it was before. It may be said that so high a water-gauge would be inconvenient, as it would generate too much steam for ordinary circumstances; but it is obvious that this could be regulated at will by an escape-pipe, whereby any surplus steam could be carried off clear of the chimney altogether.

By the proposed arrangement the evaporation of 84 cubic feet per hour could be maintained with little more than half the steam passing through the blast-pipe, whilst the other half would be always available when required, as in the case of a steep gradient or a heavy head wind.

In conclusion, the Author desires to state that he does not set forth the above results as absolutely correct. The data at his command are too limited to justify such a claim; but he believes they are approximately true, and hopes that they may be useful as pointing out the method which, if applied to more extended data, will enable others to throw greater light on a somewhat obscure subject which has important bearings on the practical construction of locomotive engines.

[Mr. LONGRIDGE

Mr. LONGRIDGE desired particularly to direct attention to the method he had introduced of separating the evaporative effects of the different parts of the boiler from each other. Hitherto, he believed the formulæ had been purely empirical, and his desire was, if possible, to bring them out of that category, and to introduce formulæ which would show with mathematical truth the real position of affairs. The only uncertainty was in the value of certain constants that had to be introduced into the formula. There was some doubt with reference to the value of the constant m, and perhaps some doubt with reference to the specific heat of the gases at the temperature indicated. Those were points not positively certain; but he had reason to think his estimates were not far from correct. With regard to the constant m, he had tried various other values to see how far they would agree with experimental results; but he had found them very far from the mark. He could confidently recommend the method of investigation adopted; but he should be glad if gentlemen who had the opportunity would institute experiments for verifying the constants. He believed there was a very general error with regard to the heating effect from tubes. It was commonly supposed that the bottom of the tube had no heating effect at all, that the sides had very little, and that only the upper semi-diameter was really efficient. He thought that must be a mistake. The heat was transmitted by radiation to every portion of the tube alike. Every portion of the tube was alike in contact with the water; and the reason why a good effect was not obtained from the surface where the tube was above the water, was that the water had not sufficient motion—that there was not sufficient circulation to bring fresh water constantly in contact with it. If there was a thorough circulation, as good an effect would be produced from the lower part of the tube as from the upper.

Mr. CRAMPTON had made some experiments on a rather large scale which bore out the Author's views with regard to high temperatures. The experiments were made with a marine boiler containing about 1,400 square feet of heating surface, with the boiler in its ordinary state. A given quantity of water was evaporated in a given time. About 9 lbs. of water were evaporated with 1 lb. of good coal, the temperature of the smoke-box varying from 500° to 800°. The experiment was continued for twenty-four hours, and, as far as he could judge, about 18 lbs. of air were consumed to 1 lb. of coal. That, of course, reduced the temperature considerably. He then took the fire bars out, and lined a portion of the round fire tubes with brick. Dust coal, together with 13 lbs.

of air to 1 lb. of coal, was then injected into three fire-boxes. The desire was to evaporate in both cases, as nearly as possible, the same quantity of water in the same time, and he succeeded within a small percentage. The same quantity of coal was burned in the same time; but the quantity of water evaporated at the high temperature was 11 lbs., as compared with 9 lbs. to 1 lb. of coal in the other case. The temperature of the smoke-box did not vary 20° during the twenty-four hours, say from 380° to 400°. With regard to the high temperature, as mentioned by the Author, the first portion of the surface evaporated more than the ordinary proportion of water, the temperature in the smoke-box being 300° to 400° less than in the other case. But there was another important element: by using the fan blast the whole of the tubes did the same duty. In an ordinary marine boiler, the chimney drew more of the combustible gases through those tubes nearest to it than through the others; whereas by having a small pressure above the atmosphere inside, the whole of the tubes were made to do the same duty. At the time of these experiments, he came to the conclusion that if perfect combustion could be obtained, using very little air above that theoretically necessary for burning the fuel, producing a high temperature, with a forced draught, the extent of boiler surface might be reduced one quarter with the same effect as compared with the ordinary system. He did not remember all the circumstances connected with the experiments; but they were carefully done on a large scale, and he believed his statement was substantially correct.

Mr. Bramwell asked whether the water given in the tables as evaporated was all from one temperature, and if so, what that temperature was; also, whether there had been an introduction of air by the fire-door over the fuel, as in the case of coal-burning engines at the present day, or whether the whole of the air for the support of combustion came through the fire-bars?

Mr. Longridge said he had no doubt that the whole of the air came through the fire-bars, but he could not say positively. In all his calculations he had assumed the water to be raised from a temperature of 60°.

Mr. Makinson thought the Author had hit upon a most valuable element, by taking into consideration the difference between the temperature of the burning fuel and of the water. The rate at which the heat could be transmitted into the boiler depended entirely upon the difference of the two temperatures, and it was an important element in the consideration of the subject.

Mr. E. Woods said the Author had treated the subject in an

able manner, presenting valuable results in a compact and useful form. He had been surprised to find that some of the questions treated of in the Paper were matters of dispute amongst authorities on locomotive engines—questions that he thought had long since been settled. His experience—not a short one—led him to agree with most of the conclusions at which the Author had arrived. It was perfectly true that no fixed ratio could be assigned as between the evaporative power of a square foot of fire-box surface and a square foot of tube surface, for the rate of evaporation varied with the difference of temperature, the difference of draught, and the rate of combustion of the fuel in the boiler. As far back as 1836 he had been associated with the Count de Pambour in some experiments on that subject, with the boilers of the Liverpool tunnel engines, which were then new. The boilers were on the principle of locomotive boilers, but the boiler part was completely detached from the fire-box, so that the evaporation of water from the fire-box could be measured as distinguished from the evaporation from the tubular portion of the boiler. The draught was produced by one of the tall chimneys at the mouth of the tunnel at Edge Hill, and it was not therefore as great as was obtainable in the locomotive engine. The first result was that, with the ordinary draught of the chimney, the fire-box surface did twenty times the duty of the tube surface; but by varying the conditions in the same boiler, by increasing the draught artificially, the ratio, instead of being 1 to 20, became 1 to 7½. No doubt if the draught had been still further increased a ratio of 1 to 3 or 4 might have been obtained. Again, the duty of various portions of the tube surface was very different. At a later period he divided a tubular boiler made for the purpose into segments, and taking the evaporation from the several segments, it was found that it varied according to the distance from the fire. Near the fire the evaporation was rapid, and at a distance it was slow, decreasing in a regular proportion. In 1853 the records were taken under his superintendence of the working of the locomotive engines of passenger trains on the London and North-Western railway during a period of a month. Some of the engines were those of the northern division of the line (Crewe engines), and the others were the larger engines of the southern section. Those engines, though different in size, in boiler capacity, in areas of fire-grates, and in proportions of fire-box surface to tube surface, were employed to do the same work; they worked certain trains alternately, so that the results might be obtained under as nearly as possible identical circumstances. There were engines with long

boilers—those introduced but afterwards abandoned by Mr. Robert Stephenson—with exceedingly long tubes; and there were also engines introduced by Mr. McConnell with long fire-boxes and short tubes. The ratio between the tube and fire-box surfaces was in the one case as 1 to 12·9, and in the other as 1 to 3·5; and in the other engines the proportions were intermediate between those two extremes. The same results were produced; the engines, whether with long or short tubes, performed the same work with the same quantity of coke, evaporating as nearly as possible the same quantity of water per lb. of fuel. It was obvious that the rate of combustion of the fuel per square foot per hour differed in the several engines; it varied from 50 lbs. to 84 lbs., but within that range the performances of the engines were practically identical. It might, he thought, be fairly inferred from that circumstance, that the Author was quite correct in his conclusion, that the proportion of fire-box surface to tube surface had nothing to do with the question of economy of fuel, and its combustion in locomotive engines. With regard to the diameter of the tubes, the object, of course, was to get the greatest extent of heating surface in the smallest space. That condition had, however, to be controlled by the considerations, that it was necessary to provide free space for the water to circulate between the tubes, and for the steam to rise between them; that sufficient area was required in the tubes for the heated gases to pass through, and it would not do to have the size so small that choking by small ashes might take place. Subject, however, to those conditions, the smaller the diameter of the tubes the better, because a greater extent of heating surface could be got into a given space. The Author stated that the heating surface should not have relation to the area of the fire-grate, but to the heat produced in a given time; but it should be remembered that the area of the fire-grate was, or ought to be, a factor of the quantity of heat developed in a given time, for if the rate of combustion were urged to too high a degree the resistance of the engine would be increased, and a more powerful blast would have to be used. There was, therefore, a limit, and that limit in practice was found to be equal to a consumption of about 84 lbs. per square foot of grate per hour. If that rate of combustion were not exceeded, a fair economy in the working of the engine would be secured. Knowing the load to be carried, the gradients to be worked over, the amount of friction or resistance to be overcome, and the speed required, it was easy to calculate what the proportions of the engine should be, taking the duty done in the best engines to be

about 355,000 foot pounds of work per 1 lb. of coal. A few simple elements alone were needed. First, there was the quantity of coal to be burned in a given time to produce the given power at the given rate; thence the area of the fire-grate could be determined; and, lastly, it was found by experience that the absorbing surface necessary to take up the heat was from 60 to 70 times the area of the fire-grate. With those data the proportions of an engine could easily be calculated. He had not been able to examine the Author's formulæ; he had no doubt they were correct; but it did not require any complicated formula to design an engine which should do a given amount of work in a given time. The subject of the blast-pipe was well deserving attention, especially of those who had an opportunity of making experiments. He did not quite think that the sub-division into different jets of steam would necessarily have the effect which the formula seemed to attribute to them, but it was desirable to ascertain by experiment the precise effect of those changes on the working of the blast.

Mr. D. K. Clark observed that, as the Author had referred to a formula which he had constructed from the results of a large number of observations for the evaporative performance of locomotive boilers, he would give some account of the data upon which the formula had been based. Table 1 [1] (pp. 142, 143) contained particulars of the proportions and performance of fifty-two coke-burning engines, or classes of engines, made with areas of fire-grate of from 6 to 24 square feet. In nearly every instance the recorded performances were the average results of several trips, comprising altogether upwards of three hundred trips. Two Papers had already been published in the Proceedings,[2] explanatory of the principles upon which the formula was constructed. It was well known that in any given boiler in which the grate-area and the heating surface were constant, and of course also the ratio of those areas, the greater the quantity of fuel consumed per hour, the greater also was the quantity of water evaporated; but that the production of steam increased at a less rate than the combustion of fuel; in other words, that the quantity of water evaporated per lb. of fuel diminished. The question had, however, remained, at what rate did this diminution

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[1] *Vide* "A Manual of Rules, Tables, and Data for Mechanical Engineers," 1877, p. 799.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xii., p. 400; and vol. xlvi., p. 242.

TABLE 1.—LOCOMOTIVE BOILERS.—PROPORTIONS and RESULTS of EVAPORATIVE PERFORMANCE.

(The fuel used was coke, except when coal was specially stated.)

No.	Name of Locomotive.	Area of Fire-grate.	Heating Surface (Tubes measured on the Outside).	Ratio of Heating Surface to Grate.	Coke Consumed per Square Foot of Grate per Hour.	Water Consumed per Square Foot of Grate per Hour.	Water Evaporated per lb. of Coke, from and at 212° F.
		Sq. feet.	Sq. feet.	Ratio.	lbs.	C. feet.	lbs.
	EARLIEST LOCOMOTIVES.						
1	"Killingworth" . . .	7·0	41·25	6·0	44·0 (coal)	2·3	4·02
2	Ditto improved .	10·9	124·0	11·4	57·0 (coal)	4·0	5·32
3	"Rocket"	6·0	138·0	23·0	35·5	3·0	6·27
4	"Phœnix"	6·0	326·0	55·0	54·0	5·7	7·86
5	"Atlas"	9·20	275·0	30·0	60·0	5·14	6·35
6	"Star"	7·76	359·0	46·0	92·0	8·22	6·53
7	Average of 4 locomotives	6·5	348·0	53·5	90·0	9·8	8·04
8	"Soho"	8·44	412·0	35·0	100·0	10·0	7·42
9					130·0	13·03	7·38
10					92·0	11·0	8·87
11	"Hecla"	8·34	418·0	49·0	125·0	11·3	6·65
12	Bury's goods locomotives	9·2	461·0	50·0	111·0	9·24	6·15
13	Bury's passenger "	9·2	387·0	42·0	112·0	8·15	4·93
	GREAT WESTERN RAILWAY.						
14	"Ixion"	13·4	699·0	52·0	138·0	15·0	8·33
15	"Hercules"	13·6	699·0	51·4	105·0	15·0	10·70
16	"Etna," "Capricornus"	11·4	467·0	41·0	97·0	10·7	8·21
17	"Giraffe"	12·5	608·0	48·6	76·0	8·8	8·61
18	"Mentor," "Cyclops" .	13·6	699·0	51·4	69·0	8·0	8·67
19	"Royal Star" . . .	11·7	822·0	70·0	91·0	10·8	8·85
20	"Pyracmon" class . .	18·44	1,363·0	74·0	69·0	8·4	9·09
21	"Ajax"	13·67	1,067·0	78·0	84·0	11·2	9·90
22	"Great Britain," "Iron Duke"	21·0	1,938·0	92·0	82·0	11·0	9·95
23	"Great Britain" variety	21·0	1,938·0	92·0	90·0	11·0	9·17
24	"Courier" variety . .	23·62	1,866.0	79·0	75·0	8·6	8·60
	LONDON AND NORTH-WESTERN RAILWAY, &C.						
25	"A," York and North-Midland Railway . .	9·6	903·0	94·0	132·0	17·0	10·52
26	"Hercules," York and North-Midland Railway	9·6	828·0	86·0	105·0	15·0	10·70
27	"Sphinx," Manchester, Sheffield, and Lincoln Railway	10·56	1,056·0	100·0	157·0	22·1	10·45
	(Later engines.)						
28	"Heron," L. & N.-W. Ry.	10·5	782·0	74·5	90·0	11·1	9·29
29	No. 291, " "	19·0	1,449·0	76·26	56·5	6·2	8·23
30	No. 300, " "	22·0	1,263·0	57·41	50·7	6·6	9·28

TABLE 1—*continued.*

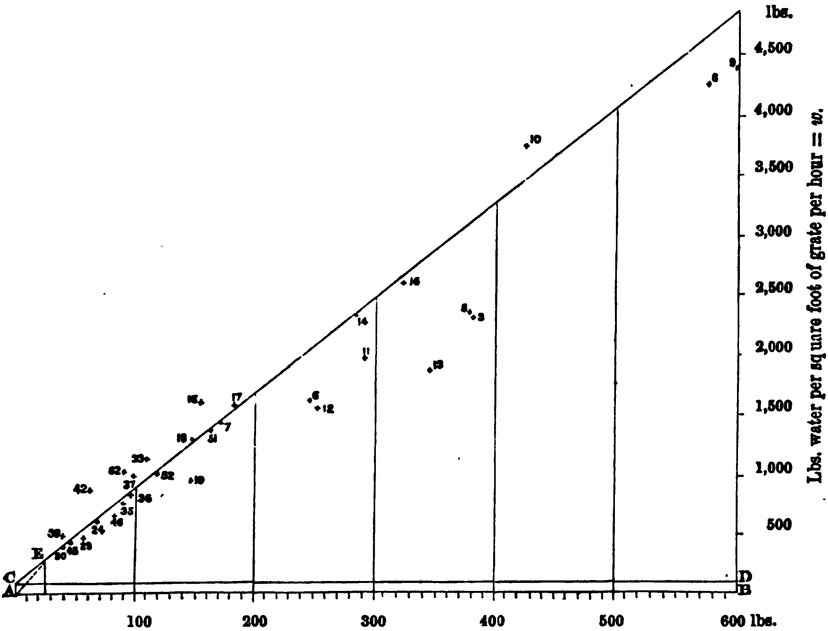
No.	Name of Locomotive.	Area of Fire-grate.	Heating Surface (Tubes measured on the Outside).	Ratio of Heating Surface to Grate.	Coke Consumed per Square Foot of Grate per Hour.	Water Consumed per Square Foot of Grate per Hour.	Water Evaporated per lb. of Coke, from and at 212° F.
		Sq. feet.	Sq. feet.	Ratio.	lbs.	C. feet.	lbs.
	SOUTH-EASTERN RAILWAY.						
31	No. 142	14·7	1,158·2	78·8	55·71	7·73	9·77
32	No. 105	10·5	623·1	59·3	55·91	9·43	11·68
33	No. 9	10·5	623·1	59·3	66·19	10·0	10·96
	LONDON AND SOUTH-WESTERN RAILWAY.						
34	"Snake"	12·4	985·0	79·0	87·0	12·26	10·59
	"Canute" (coal burning locomotive):—						
35	"Canute," feed-water heated, tiles . . .	16·0	871·0	54·4	46·0	6·46	8·76
36	"Canute," feed-water heated, no tiles . .	16·0	871·0	54·4	49·0	7·17	9·13
37	"Canute," cold water, no tiles	16·0	871·0	54·4	54·0	8·69	10·04
	CALEDONIAN RAILWAY, &c.						
38	No. 33, Caledonian Ry.	10·5	831·0	79·0	42·0	7·0	12·46
39	No. 42, "	10·5	788·0	75·0	57·0	7·8	10·11
40	No, 43, "	10·5	788·0	75·0	61·0	9·2	11·31
41	No. 51, "	10·5	788·0	75·0	45·0	6·7	11·04
42	No. 13, "	10·5	788·0	75·0	108·0	11·6	8·09
43	No. 13, "	10·5	788·0	75·0	57 0	8·2	10·71
44	No. 13, "	9·0	788·0	87·6	102·0	14·7	9·52
45	Nos. 125, 127, "	11·37	1,050·0	92·0	66·0	8·66	9·72
46	No. 102, "	11·8	974·0	82·5	94·0	10·3	8·15
47	"Orion," "Sirius," E. & G. Railway . . .	12·23	758·0	62·0	44·0	6·29	10·71
48	"America," "Nile," E. & G. Railway. . . .	11·10	736·0	66·3	70·0	8·8	9·31
49	"Pallas," "	16·04	818·0	51·0	38·0	6·0	10·47
50	"Brindley" " . .	9·15	802·0	87·65	54·0	7·2	9·94
51	"Orion," G. & S.-W. Ry.	9·24	495·0	53·6	84·0	9·4	8·28
52	"Queen," "	10·5	688·0	65·5	87·0	10·0	8·57

of efficiency take place? The answer was supplied by the fact, generalised from experimental observations on stationary, portable, marine, and locomotive boilers, that the quantity of water, w, evaporated per square foot of grate was expressed by a constant quantity A, plus a constant multiple B c, of the fuel, c, consumed per square foot of grate; according to the general equation

$$w = A + B c.$$

The sense of this equation was, that whilst the proportion of the water evaporated per square foot of grate did not keep pace with the fuel consumed, yet the quantity of water increased by equal increments for equal increments of fuel per square foot of grate. Fig. 3 was a geometrical representation of the law. The straightness of the diagonal line indicated it.

FIG. 3.



Performance of locomotive boilers. Relation of coke consumed and water evaporated. Reduced for the proportion of the heating surface, 75 times the grate area. $w = 100 \times 7{\cdot}94\ c$.

The great principle of the formula, which had been investigated in his Paper of 1853, was that in maintaining constant evaporative efficiency of the fuel, that was, when the same proportion of water was evaporated per lb. of fuel, the total evaporative capacity of the boilers increased directly as the square of the heating surface, and decreased directly as the area of the grate increased. As a consequence, the water evaporated per square foot of grate per hour under those conditions, increased as the square of the surface-ratio, that was, as the square of the ratio of the heating surface to the grate-area. The general equation took the following form, embracing the two principles—

$$w = ar^2 + \mathrm{B}\,c,$$

or, for locomotives burning coke,

$$w = \cdot 0178\, r^2 + 7 \cdot 94\, c \text{ (coke)}.$$

c = the quantity of coke in lbs. consumed per square foot of grate per hour.

w = the equivalent quantity of water evaporated in lbs. per square foot of grate per hour, from and at 212° Fahr.

r = the surface-ratio, or the ratio of the heating surface to the area of grate.

With so many and varied proportions of heating surface to fire-grate area as were shown in the table—from a heating surface six times the grate to a surface one hundred times the grate—it was necessary to reduce all the performances to the equivalents for one standard surface-ratio, in the proportion of the squares of the surface-ratios, in order that they might be directly compared. The standard ratio 1 to 75 had been adopted for coke-burning locomotives, and the resulting equivalents had been placed as stars in Fig. 3. The base-line A B represented the quantity of coke consumed in lbs. per square foot of grate per hour, reduced for the ratio 1 to 75. The vertical distances of the stars measured the corresponding equivalent quantities of water evaporated from and at 212° in lbs. per square foot of grate per hour for each case; the quantities of fuel being measured by the horizontal distance from the end A. The parallel line C D was drawn through the point C, where the diagonal cut the vertical from A. It measured the constant quantity of water, $\cdot 0178\, r^2$ in the formula, which, for the surface-ratio 75, amounted to 100 lbs.

The old Killingworth engine, it might be observed, stood at the extremity of the scale. It was constructed at first with only 41½ square feet of heating-surface, which was increased to 124 square feet, with 10·9 square feet of grate, giving the ratio 11·4. Taking the improved Killingworth engine, the amount of coal consumed per square foot of grate per hour was 57 lbs., and the water evaporated per lb. of coal was 5¼ lbs. from and at 212°. To reduce this performance to the equivalent for a ratio of heating surface seventy-five times the grate, the fuel and water were raised in the ratio of

$$11 \cdot 4^2 \text{ to } 75^2;$$

and the equivalent quantities were

2,467 lbs. of coal, and 13,120 lbs. of water.

But, as in early locomotives, coal only evaporated two-thirds as much water as coke could have done, the quantities, as for coke, would have been 1,644 lbs. per square foot of grate, and 13,120 lbs. of water. These quantities exceeded the limits of the diagram, and were therefore not shown. The correspondence of the reduced evaporative performance with the principles of the formula, was easily shown by calculating it thus, according to the formula:—

$$w = (\cdot 0178 \times 11^2 \cdot 4) + (7 \cdot 94 \times 1{,}644 \text{ lbs.}) = 13{,}052 \text{ lbs. of water},$$

which amount was nearly identical with the quantity above computed in the ratio of the squares. It need scarcely be explained that these values for the Killingworth engine, and in fact the reduced values for many others of the engines plotted on the diagram, were merely constructive values. They were introduced to show that the principle of the formula extended over the widest range of practice, with a remarkable degree of truthfulness. It might be noted that the two Bury engines, Nos. 12 and 13, stood considerably within the range of the diagram. When it was considered that these were the original four-wheeled engines of the London and Birmingham railway, that they consumed 1 cwt. of coke per hour on a square foot of grate, that they danced about on the line, and pitched unburned fuel through the tubes, the marked inferiority of their evaporative performance was easily accounted for. The formula which he had deduced for the evaporative performance of locomotive boilers consuming coke, as well as the formula for those consuming coal, implied the use of good fuel and sufficiently free circulation of water and steam within the boiler.

The Author had made a calculation by means of Mr. Clark's formula in a case to which it did not apply, showing an evaporation of 23½ lbs. of water per lb. of coke. In explaining the formula in a recent paper[1] Mr. Clark had defined the limits of its application, and pointed out why it could not apply for rates of combustion lower than certain specified amounts per square foot, near the beginning of the scale, since the fuel could then but deliver the whole of its heat to the water, and no more. In the case of a surface-ratio of 1 to 75, exemplified in the diagram, the limit was 25 lbs. of coke per square foot per hour, and the dotted line E A was the proper continuation to the end of the base-line. Having

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlvi., p. 268.

regard to these limits, no such calculation of impossible quantities could properly be made.

The Author had given, in Table B, p. 108, in parallel columns, the actual evaporative performance of several of the locomotives embraced in the Table submitted by Mr. Clark, together with the performances as calculated by his formula and by Mr. Clark's formula. It would be observed that the values calculated by the latter formula were much more closely approximative than those deduced by the former. Indeed, the generally close approximation by Mr. Clark's formula, with some exceptional instances already referred to, was shown by Fig. 3. On the contrary, the values calculated by the Author's formula exhibited so numerous and so wide divergencies as to induce the conviction, that it did not contain all the elements essential to a professedly scientific formula. There was, in fact, a serious, and indeed a fatal omission from the elements of the Author's formula; it did not recognise the action of radiant heat, which might be discharged from the surface of the fire and be delivered upon the plate-surface of the fire-box, without raising the temperature of the products of combustion of coke which rose into the fire-box. It was deducible from the experiments of Messrs. Dulong and Petit, that the proportion of the total generated heat delivered as radiant heat increased in an extremely accelerated ratio with the temperature of the surface of the fire; so much so, that it was physically impossible that any temperature of the heated gases, even approaching 2,450° Fahr., as stated by the Author, could be attained. Daniell's pyrometer, the instrument employed by him, consisted of a metal bar enclosed in a case of black-lead earthenware; and unquestionably it must have absorbed a portion of the radiant heat, and its indication of temperature must have been considerably higher than the temperature of the gases. It might have been true, as stated by the Author, that Pouillet observed temperatures even higher than that observed by the Author; but the furnaces tested by M. Pouillet were reverberatory furnaces, which were of a very different order from locomotive furnaces, where the temperature of the enclosure did not exceed 400° Fahr.

The Author questioned the conclusiveness of Mr. Clark's argument in 1853, that coke was, under good management, completely burned in a locomotive fire-box. His argument[1] had been based on the datum that when the temperature in the smoke-box did not exceed 600° Fahr., 9 lbs. of water could be evaporated per lb. of good

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xii., p. 386.

coke, allowing 8½ per cent. of ash and water in its composition. It was only too easy to prove perfect combustion. That the temperature in the smoke-box was usually 600° or more, he found to his cost by the evaporation of large quantities of mercury in the course of his experiments to test the temperature.

He must confess to a feeling of surprise that the Author should maintain that the proportion of the area of the fire-grate to the heating surface was not of any practical importance. He did not consider it necessary to go into the details of the evidence on this point, for, in his opinion, it did not now admit of question. He might refer to his Paper of 1853, in which ample evidence had been produced in support of the principle, that the proportion of grate to heating surface was a vital economical factor in the evaporative performance of locomotive boilers, as well as of all other classes of boilers.

He would only add that the recorded performances of the portable-engine boilers at Cardiff, in 1872, analysed in his Paper on steam-boilers,[1] distinctly corroborated his assertion of the necessity for proportioning the grate-area for the most efficient performance. It was sufficient to notice that the portable engines which secured the prizes were those in which the area of the fire-grate was considerably reduced, and carefully proportioned to the heating surface. It might be, and was no doubt, true, that the circumstances of ordinary practical work demanded other proportions, but this was quite a different question.

Mr. Bramwell said the Institution, he thought, could not be more worthily occupied than in considering, from time to time, the question of economy in steam power. He was glad that, on the present occasion, that question had taken the form of economy in the generation of steam, a question which was too commonly neglected, while the utilisation of the steam produced was the subject pursued. But, with Mr. Woods, he was somewhat surprised that the Author was now considering the subject as to the relative value of fire-box surface and of tube surface. For many years past Mr. Bramwell had held that it mattered very little what shape the surface took so long as there was enough to absorb the heat given out by the fuel and to transmit it to the water. He did not wish to be misunderstood as saying that, on other grounds, the form of surface was indifferent; because, of course, it was necessary to have through the tubes sufficient area for the draught, and between the tubes sufficient space for the circulation of water and for the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlvi., p. 263.

passage of the steam produced, and also in determining the form of surface, safety must be considered. Moreover, it was most important that the boiler should be so designed as to give an adequate area from which the steam could rise tranquilly and so as not to produce priming. He agreed that all those matters were vital and must be taken into consideration in designing a boiler; the nature of the surface, therefore, in that way became important. But he did not think, so far as economy in fuel was concerned, that it was a matter of any importance what the nature of the surface might be, so long as there was enough of it to convey the heat to the water. Entertaining such opinions as these he was quite prepared to follow Mr. Woods' statement with reference to experiments made years ago at Edge Hill, where in a boiler of the locomotive type, fitted up for the experiment, the ratio of effect of a foot of fire-box surface was found to be very large compared with that of the tube surface when the boiler was doing but little, as the fire-box surface was then sufficient to absorb the greater part of the heat, and did not leave much to go to the tubes; but when the duty of the boiler was increased, even within the ordinary limits, the fire-box surface, being no longer competent to absorb the increased heat, left more to go to the tubes, and thus the ratio was altered. It appeared to him, therefore, that the ratio of useful effect between fire-box surface and tube surface, varied from time to time, and was not solvable, and not of any real importance. Unhappily, the Author's tables and Mr. Woods' experiments related to a time, when, in locomotives, coke was the fuel employed, and when the whole of the air required for combustion came through the fire-bars. At that time, no doubt, the area of the fire grate was a matter of some importance; but now that coal was the fuel, it was necessary to find means to burn the smoke. Those means had settled down practically into the brick arch and the deflector, admitting air through the opening of the fire door on the gases evolved in the fire-box, so that only a comparatively small portion of the air went through the fire-bars. He thought the importance of the area of the fire-grate had thus been much diminished, and that the area might be varied within large limits without practically affecting the result. When fuel was in combustion, the active part was clearly only the surface of the fuel. Now, fuel might exist in four states—four that he knew—and it might exist in more that he had not thought of; as a gas, as a liquid, as a solid, but as a solid reduced into fine powder, as by Mr. Crampton's system, or in the ordinary condition of blocks and pieces of coal of various sizes. Reverting to the ordinary condition, that of

blocks and pieces of coal, supposing the pieces of coal to be 1 cubic foot each, the surface of each such piece would be 6 square feet, and he would suppose, for the sake of illustration, the weight to be 100 lbs. Such a piece of coal only entered into combination with the oxygen of the air by means of its surface, and was therefore giving off no more heat in an equal time than would be given off by four blocks 6 inches square, containing among themselves 6 feet of surface; but having an aggregate weight of only 50 lbs. instead of 100 lbs. Therefore, by breaking up coal into pieces of that size, the heating effect produced in a given time by a given weight of fuel was immediately doubled. With regard to fuel in the form of gas, the surface of the gas was, so to speak, infinite, and, it might be, united with the air very rapidly—so rapidly indeed that if the air were mixed to begin with, an explosion occurred, because the action between the air and the gas was instantaneous. With reference to fuel in the liquid state, the surface, though it could hardly be said to be infinite, was very large, and there might be an intense action in a small space by the mixture of the liquid and the air. Again, where the coal was broken up into powder, the surface was multiplied so enormously in proportion to the solid particles, that an intense action might be obtained in a small space. Those three modes of dealing with fuel were absolutely irrespective of any question of fire-grate. The air and fuel went in intermixed and did not require a grate at all. But with the ordinary mode of using fuel the fire-grate area was of importance so long as the whole of the air was introduced through the bars, and was so for an obvious reason. In order to obtain a sufficient amount of surface of fuel in action at once, looking at the limited surface of the pieces of fuel compared with the weight, it was necessary to have a certain mass of fuel in the fire-box. If it were piled too high upon the fire-bars there were two difficulties: one, that the air could not be got to draw through it; and the other, that if it could be, the air which entered was all used to convert the carbon in the lower part into carbonic acid, and there no longer remained free air. In fact, the carbonic acid in passing upwards through the fuel became converted into carbonic oxide, and carried away with it a large portion of the fuel unconsumed. But such loss must not be permitted, and thus it was necessary to diminish the depth of the fuel and to increase the area of the fire-bars. Under these circumstances there was a point, as Mr. Woods had shown, beyond which it was not possible with economy to burn off a given weight of fuel per foot of grate-bar. But when, as with the locomotive boiler of the present day, coal was used, and only

enough air was let in through the bars to convert the coal into carbonic oxide, the rest of the air, coming through the fire-door, above the fuel converting the carbonic oxide into carbonic acid, then, as he had said, the importance of the ratio of the fire-grate to the fuel burned was much diminished, and the proportions might be varied within large limits without any evil effect.

It would be well for the engineering profession if owners of locomotive engines were to agree to do that which, for years past, had been done by the Royal Agricultural Society—to have from time to time, competitions of locomotive engines, with the object of putting upon public record their real evaporative duties and other qualities, and with the object also of training stokers in the proper mode of firing. The results of that kind of competition in the improvement of the ordinary agricultural engine, which generally had a boiler of the locomotive type, had been most marked. Table 2 (p. 152) was compiled from Tables of the results of trials made by the Royal Agricultural Society. Some of the columns were to be found in that Society's publications, but the others, though compiled from the same source, were not to be found there. The original table was an elaborate one, because it entered into the whole question of the generation of the steam, of the utilisation of the steam when produced, and the question of the results obtained from that utilisation. It took in, therefore, both the boiler and the engine. But, as the discussion on this occasion only turned upon boilers, he would limit himself as regarded the engines to saying that the best showed a consumption of less than 2½ lbs. of coal per hour for 1 gross indicated HP. and a realisation of HP. on the brake equivalent to a Cornish duty of 79,000,000. He would ask the members to compare this duty of a non-condensing engine working at 80 lbs. to an inch with the duty of Cornish engines, as stated in "Lean's Reporter" for December 1877. In that publication sixteen engines were reported on, and it appeared that their average duty was 47,700,000, while that of the best was only 65,100,000. With respect to the table exhibited by him, he desired to call attention to some great discrepancies in the proportion of the parts which were not accompanied by corresponding discrepancies in the economic results. All the engines were 8-HP. nominal, as shown by column 2. The makers were invited to try their engines at any power they pleased so long as it was not less than the nominal; and it appeared by column 3 that they elected to try them at 14, 14, 14, 8, 12, 9, 12, 17, 14, 20, 12, 8, and 12; so that in one case alone was the trial power as low as the nominal. The grates varied from 3·2 to 7·2 superficial feet. But when the engines

TABLE 2.—COMPILED from TABLES of TRIALS of PORTABLE ENGINES, ROYAL AGRICULTURAL SOCIETY, CARDIFF, 1872.

Boilers all "Locomotive type," except M, which was a vertical boiler with circulating water tubes.

Fuel, Llangennech coal. Theoretical evaporative power from 60° = 13·2 lbs.

1	2	3	4	5	6	7	8	9	10	11		12		13		14		15	16	17	18	19
	Nominal HP.	HP. developed on Brake.	Ordinary Area of Fire-grate.	Area of Grate as used diminished by Brick-work.	Heating Surface in Fire-box.	Surface in Tubes and Smoke-box.	Total Heating Surface.	Ratio of Total Heating Surface to ordinary Fire-grate Surface.	Ratio of Total Heating Surface to Area of Fire-grate used.	Total Evaporation per Hour from 60°.		Evaporation per Square Foot of Heating Surface.		Evaporation from 60° per lb. of Coal.		Evaporation per Hour per Foot of Fire-grate actually used.		Lbs. of Coal Burnt per Hour.	Lbs. of Coal Burnt per Hour per Square Foot of Fire-grate actually used.	Lbs. of Coal Burnt per Hour per Foot of Heating Surface.	Temperature of Gas in Smoke-box.	Ratio of Duty obtained from the Coal as compared with its Theoretic Value.
			Sq. ft.	Sq. ft.	Sq. ft.	Sq. feet.	Sq. feet.			C. ft.	lbs.	C. ft.	lbs.	C. ft.	lbs.	C. ft.	lbs.	lbs.	lbs.	lbs.		
A	8	14	4·4	3·0	26·3	257·2	283·5	64	94	6·5	417	·022	1·4	·142	8·86	2·17	139	47·2	15·7	·16	..	·671
B	8	14	5·3	3·2	25·4	194·8	220·0	41	70	6·5	419	·030	1·9	·164	10·24	2·00	131	41·0	12·8	·18	360° to 418°	·776
C	8	14	5·3	3·2	25·4	194·6	220·0	41	70	6·3	409	·029	1·8	·164	10·23	1·99	129	40·0	12·5	·18	390° to 415°	·775
D	8	8	5·1	5·1	28·6	142·0	170·6	33	33	4·7	296	·027	1·7	·063	3·93	0·92	58	75·5	14·8	·43	548°	·300
E	8	12	6·13	2·0	30·0	163·0	193·0	31	96	..	..	..	..	..	..	..	..	38·3	19·15	·50	..	..
F	8	9	3·2	3·2	19·8	139·3	159·1	50	50	4·6	287	·017	1·1	·151	9·43	1·46	90	30·5	9·53	·19	385°	·714
G	8	12	4·7	4·7	27·8	130·2	158·0	34	34	7·9	493	·050	3·1	·127	8·08	1·61	105	61·1	13·0	·38	About 600°	·612
H	8	17	7·2	2·37	39·4	171·6	211·0	29	89	7·0	438	·032	2·0	·145	9·08	2·53	185	48·3	20·4	·23	425° to 435°	·688
I	8	14	4·3	1·6	24·4	127·2	151·6	35	94	..	..	..	..	..	..	..	..	56·2	35·1	·37	..	..
J	8	20	3·5	3·5	18.8	169·0	187·8	54	54	10·0	622	·052	3·3	·137	8·60	2·86	177	72·4	20·7	·38	500°	·651
K	8	12	5·0	5·0	27·4	102·4	129·8	26	26	8·3	522	·051	3·2	·124	7·77	1·66	104	67·2	13·6	·52	Over 600°	·588
L	8	8	5·5	2·0	27·8	176·7	204·5	37	102	8·0	499	·038	2·4	·128	8·03	4·00	249	62·2	31·1	·30	At end of run 360°	·608
M	8	12	3·75	3·75	35·4	133·0	168·4	45	45	5·9	370	·044	2·8	·152	9·54	1·71	100	38·8	10·3	·23	320° to 380°	·723

were under trial, the men who worked them and knew their business did not desire to avail themselves of that large grate-area, and by means of fire-bricks laid over the bars round the sides of the fire-box they reduced the areas, as stated in column 5, to a variety of dimensions. One of them had been reduced from 6·13 feet to 2 feet; another from 5·5 to 2 feet. Columns 6 and 7 gave the heating surfaces in the fire-boxes and tubes; column 8 gave the total heating-surface; column 9, the ratio of the total heating surface to the ordinary fire-grate; and column 10 the ratio of the total heating surface to the fire-grate actually used, that ratio varying from 26 to 102. The coal employed in all cases was Llangennech, which was analysed, and the theoretical value of it in boiling off water from 60° was 13·2 lbs. Column 13 showed the evaporation from 60° per lb. of coal in cubic feet and in lbs. It ranged from as little as 3·93 lbs. in one engine to as much as 10·24 lbs. in another. Column 16 showed the lbs. of coal burned per hour per square foot of grate actually used, ranging from 9½ to 31 lbs. The weight of coal burnt per foot of heating-surface (column 17) ranged from ·16 lb. to ·52 lb. The temperature of the gases in the smoke-box was given in most cases; and column 19 showed the ratio of duty done to the total duty that the coal could have theoretically given. On comparison it would be found impossible to deduce any law whatever from the relation between the coals burnt per foot of grate bar and per foot of heating-surface; but it would be found, as might be expected, that where the surface was insufficient to absorb the heat, and the gases went away from the smoke-box at a high temperature, there was a comparatively poor result. He had advised (being one of the judges) the collection of samples of gases, in order that they might be analysed; but he was sorry to say he had not been able to educate the Council of the Society up to that point. They had agreed to everything else, but could not see the use of bottling up smoke and analysing it. For himself, he thought it was important, because he held that the whole secret of the success of the evaporative experiments was due to the extraordinary care given in firing. The average consumption of fuel per boiler per hour was only about 28 lbs; and yet those 28 lbs. were put on by as many as thirty firings an hour. By carefully manipulating the ash-pan damper, the men succeeded in letting through just the amount of air that gave perfect combustion without too much lowering the temperature of the gases produced. In practice it was not possible to afford to put on coal in that manner, because the wages of the men would be far in excess of anything that would be saved; but the result, he thought, showed that the endeavours of engineers should be

directed to firing by some mode admitting of mechanical, and therefore of regular, treatment. What was wanted was an intelligent machine to do that which was done by an intelligent man. Gas, liquid fuel, and powdered fuel were all eminently capable of being treated by mechanical means, so as to insure a due admixture of air. Mr. Crampton had already said that the results he had obtained were attributable to such due admixture of air. Taking the ordinary fuel, he believed it would be well if attention were again seriously directed to the now almost uncared for plan of mechanical fire feeding. With regard to the engine, which only evaporated 3·93 lbs., he might say that it was an engine of excellent workmanship, nicely painted and very good-looking—an engine that many farmers, and even many engineers, would have readily bought. It was not, however, skilfully designed or skilfully worked, and the result was that it only evaporated about 4 lbs. of water, while the others were evaporating 8 or 10 lbs. There was only one engine (which he had placed at the bottom of the list) that had not a boiler of the locomotive type. Its boiler consisted of a vertical fire-box with internal circulating tubes; but it would be seen that it boiled off 9½ lbs. of water per hour per lb. of coal, approaching closely the highest result obtained from the other boilers, and being largely in excess of many of the results given by the locomotive type. He mentioned this in support of his views, that it mattered little what was the form of heating-surface, so long as there was enough to absorb the heat. In 1873 Dr. Russell and he made some experiments upon a boiler of this construction at the International Exhibition, but they had been too busy to have them tabulated at the time. Within the last few days, however, he had been corresponding with Dr. Russell on the subject, and the result was given in Table 3, p. 155, headed "Balance Sheet." He had so named it because it was compiled in a way in which he thought persons desirous of criticising the behaviour of fuel in a boiler should deal with the results and ascertain their profits and losses. The fuel employed was ordinary gas coke, which, although it was lying in a covered shed outside the building, was found to have absorbed more than 10 per cent. of moisture. The plan of trial pursued was practically that adopted by the Royal Agricultural Society. Steam was got up, and the boiler was worked for a short time with the steam at 53 lbs.; the water being at the right level in the water-gauge. Under those circumstances the hot fuel was drawn out and was put into a bucket and weighed, and then put back again with 10 lbs. of wood. The coke had been previously weighed out in parcels of 14 lbs. each; and the time when each parcel was finished, and when each measure of water

Dr. TABLE 3.—BALANCE SHEET. DURATION of EXPERIMENT, FOUR HOURS TWELVE MINUTES. *Cr.*

	lbs.		lbs.	lbs.	lbs.
To gas coke	228·25	By water in coke	24·08		
„ wood	10·00	„ ash „	10·33		
		„ hydrogen, oxygen, nitrogen and sulphur	3·42		
				37·83	
		„ water in wood	2·00		
		„ ash „	0·20		
		„ hydrogen „	0·49		
		„ oxygen „	3·27		
				5·96	
					43·79
		Balance being useful combustible			194·46
	238·25				238·25

	Heat units.		Heat units.
To balance of useful combustible brought down 194·46 × 14,000 (units of heat per lb. of coal) =	2,722,440	By 3,330 lbs. of air (being $17\frac{1}{8}$ lbs. of air to 1 of carbon) raised from 60° to 700° (the temperature of the outgoing gases), 3,330 lbs. × 640° × ·2379 =	506,880
		„ 26·08 lbs. of water in fuel turned into steam and raised in temperature	36,251
		„ radiation and conduction in the four hours twelve minutes =	70,430
		„ 1,620 lbs. of water raised from 60° and turned into steam at 53 lbs. pressure, 1,620 × 1,145 =	1,854,900
			2,468,461
		Unaccounted for	253,979
	2,722,440		2,722,440

TABLE 3—*continued*.—TEMPERATURE in FLUE DURING EXPERIMENT.

H. M.		Fahrenheit.
1 0 P.M.	. . . .	670°
1 50 „	. . . .	610°
2 55 „	. . . .	750°
4 0 „	. . . .	770°
4 24 „	Experiment stopped.	

The temperature of the air was 70°. The reading of the barometer was 30·07 inches.

ANALYSIS of GAS in FLUE.

—	Before Firing.	After Firing.	Between Firing.	Average.
	Per cent.	Per cent.	Per cent.	Per cent.
Carbonic acid	9·42	12·91	10·19	10·84
Oxygen	11·16	7·16	10·16	9·49
Nitrogen	79·42	79·93	79·65	79·67
Combustible gas . . .	..	..	Trace	..
	100·00	100·00	100·00	100·00

was used, were noted. This recording of the steps of the experiment formed a useful check. At the end of the experiment, having got the fire in as nearly as possible the same condition, and having taken care that the water was the same height in the gauge, and the steam at the same pressure as at the commencement, the fuel was drawn from the fire-box and weighed. The experiment was sufficiently well conducted, and there was only a difference of 1 lb. between that which was drawn out on the first and that drawn out on the second occasion. The total consumption in the four hours and twelve minutes over which the experiment extended was 228¼ lbs. of coke and 10 lbs. of wood. On analysing, it was found that the 228 lbs. of coke contained 24 lbs. of water and 10½ lbs. of ash. Deducting these, and the water, &c., in the wood, there remained 194 lbs. of carbon, which amount was the balance to the debit of the boiler. Multiplying that by 14,000 heat units, the result was 2,722,440 heat units which he was bound in some way to account for. An anemometer was placed in the opening to the ash-pan in different parts, and thus the amount of air that went in was known. A thermometer was placed in the chimney and samples of gases were taken from the chimney and analysed. The water fed in was weighed. The precaution was taken of ascertaining that they were getting dry steam and were not attributing to the boiler as evaporation that which was really priming. For this purpose a vessel, the specific heat of which was known, containing

100 lbs. of water, was employed, and steam from the boiler was blown into it and raised the water to a given temperature; then the weight of the water and the condensed steam was taken, and in that way it was ascertained whether the steam which came out and heated the water was dry or wet. It was found to be perfectly dry. When the experiment was concluded, the ash-pan damper, the fire-door and the chimney damper were closed; and they then observed the pressure of the steam and noticed how long it was in cooling down to different reductions of pressure. The object was to find the loss of heat by radiation and conduction from the surface of the boiler itself. By the use of all these means they were pretty well prepared to give some account of what became of the 2,700,000 units of heat. In the first place 3,330 lbs. of air had been admitted to the fire, or 17⅛ lbs. per lb. of gas coke used and nearly 20 lbs. per lb. of carbon used. The temperature of the chimney was far too high, averaging 700°. The air was at 60°; the gases, therefore, had been raised 640°. Multiplying that number of lbs. of air by the increase in temperature and by the specific heat of the air, it appeared that half a million units of heat went up the chimney in the shape of escaping gases. Then there were 26 lbs. of water in the fuel, which had to be turned into steam and raised in temperature to that of the escaping gases. That demanded 36,000 units. Next there were lost by radiation from the boiler 70,000 units; then 1,620 lbs. of water were turned into steam, taking up 1,854,000 units, that being the useful duty of the boiler. These heads accounted for 2,500,000 units in round numbers, leaving about 250,000 units unaccounted for. He should have been glad if his avocations had enabled him to pursue the inquiry at the time, and to present a more accurate balance sheet with a smaller item unaccounted for; but he believed a balance sheet of that sort was that which a person ought either to construct or to have mentally before him in considering what had been done with the coals employed under a boiler. The Author had spoken of the rate of transmission of heat per square foot per degree per hour, and had stated that Peclet's experiments showed that it ranged from 100 to 1000 heat units under certain circumstances. But such a rate could not be true for boilers, and he had put it at 11 units. The Author had taken this uniformly throughout the whole boiler as the rate of transmission per degree of difference of temperature, and had done this for high and low temperature alike. There would be found in the Minutes of Proceedings of the Institution,[1] a statement by

[1] *Vide* vol. xxxv., p. 37.

Mr. Anderson, in his Paper on the Aba-el-Wakf Sugar Factory, and some remarks by himself, showing that when steam was on the one side of a conducting surface and a liquid to be heated on the other, there were about 200 units of heat per superficial foot per degree of difference of temperature per hour up to the point when the ebullition was reached in the fluid that was being heated. As soon, however, as that ebullition was obtained, the 200 units became converted in his experiments into 460 units, and in Mr. Anderson's into 600 heat units; but he believed that the vessel experimented with by himself was, in an inaccessible part of it, somewhat coated with scale. But Mr. Anderson had stated[1] that where steam or water was on one side and the air upon the other, the transmission per degree of difference per superficial foot was as low as $2\frac{1}{8}$ units, when the difference in temperature was only 50°, and when the outside temperature was as low as 60°; and that it was raised to $3\frac{1}{8}$ units per degree, when the difference reached 200°. Mr. Anderson gave a curve showing that the rate of transmission was not uniform per degree of difference, but that it varied as the difference varied. He thought it therefore extremely likely that the Author, in taking 11 heat units all over, had not been accurate, although no doubt he had given a correct representation of the average results of the fire-box and tubes together. In conclusion, he found he had omitted to call attention to the analysis of the escaping gases taken during the experiment at the International Exhibition. It would be found from Table 3, that in one hundred parts the free oxygen remaining was, on different occasions, 11 per cent., 7 per cent., and 10 per cent., and that in no case was there any combustible gas, except in the third of the analyses, where there was said to be a trace, and that took place immediately after firing. He wished to add that as perfection could not be obtained in hand firing, it was far better to err upon the side of letting in too much air than upon that of letting in too little, more especially when the boiler was in other respects well constructed, and when the gases escaped at a low temperature. He would give an illustration. Assuming that it required theoretically 12 lbs. of air per pound of carbon, by shutting out 0·85 lb. of air, $\frac{1}{7}$ lb. of carbon would remain as carbonic oxide, giving only 4,000 units, instead of being converted into carbonic acid, giving out 14,000 units, causing a loss per lb. of fuel burnt of, in round figures, 1,400 units. The admission of double the required air, if the gases were escaping from the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlviii., p. 260.

funnel at as high a temperature as 560° would only cause the same amount of loss. If, on the other hand, the gases were escaping at a much lower temperature, say 310°, the letting in of double the required amount of air would only cause half the amount of loss that would be caused by excluding about one-fourteenth of the air theoretically required. If, therefore, there was to be error, it should be on the side of too much air rather than of too little. But his advice was, as he had said, that engineers should seek those modes of combustion which would enable them to use mechanical firing, and thus dispense with all error in proportioning the air to the fuel.

Mr. E. Reynolds ventured to offer a few words of criticism on the Paper. It often happened that communications of that kind, highly scientific as they appeared to be, were of little practical use. He did not know that the Paper would help any locomotive engineer to design a boiler. He had been frightened at the array of figures, and the value of the constant *m* made him think that the subject was out of his province altogether. He could not even assent to all Mr. Bramwell's remarks. He did not think there was any necessity in locomotive work for the kind of competition which had been alluded to, because every day's work of every locomotive engine was analysed, and men were promoted, to a large extent, by their merits in the economy of fuel. The locomotive boiler had grown up by natural selection on the principle of the survival of the fittest type. Few scientific engineers used figures in designing boilers. They knew pretty well what a boiler ought to do, and successfully worked up to it. Mr. Bramwell had touched upon an essential point in the construction of a locomotive boiler—the importance of getting a sufficiently large area of water level for the steam to be released without priming, and he thought that many of the discrepancies in the results tabulated in the Paper had reference to that point. Certain engines of the Great Western Railway Company had been referred to, showing an evaporation between 20 and 25 per cent. less than it ought to have been according to the formula, while with other engines it was more. These however, were typical engines of their time. About the time when the experiments were made he had gone round to the different railways, and had been permitted by Mr. John Gooch, of the South-Western, and Mr. (now Sir Daniel) Gooch of the Great Western, to inspect the the coke sheets. He then found that the "Iron Duke" class of engine was working with extraordinary economy, although it appeared by the table to have done 25 per cent. less work than the "Snake" class of the South-Western. He was reminded of a

remark recently made by Mr. Holt,[1] with reference to indicator diagrams, who said they ought not to be too much relied on: they might be used as instructive assistants; but the best plan was to go by results. The very engines which appeared from the table to be doing less than the proper amount of duty, used to take their trains at a cost of fuel per ton per mile smaller than almost any others; and, although the broad gauge was dying out, they still held their own against modern improvements. In many of the experiments, one matter to which Mr. Bramwell had referred had not been carefully attended to—the ascertaining whether the steam was really dry or not. When the "Jenny Lind" engines were introduced, they had about one hundred and twenty-eight 2-inch tubes. After they had been in use about a year, they were altered by the insertion of two more rows of tubes, but the universal report amongst the engine-drivers was that the locomotives would not pull so well, because the area of the water level was reduced, and the steam was not dry. The last time he saw the late Mr. W. Bouch, that engineer was still making long-boiler engines, and the reason assigned for it was that they were mineral engines, for working on inclines, and that they carried the water better. It was the old tale—the importance of a sufficient area of water level. If the water really evaporated could be separated from that thrown off by priming, it would be found that the "Snake" class of engine, good as it was, lost a considerable amount in that way. Those who had charge of boilers with plenty of heating surface and numerous tubes, knew what difficulty there was in working with them, and how much greater efficiency could be obtained with less heating surface. With regard to the proportion of grate to boiler surface, it was true that, within limits, it did not much matter what the proportion was; but there was a certain rate of combustion which produced a maximum intensity, and everything beyond that would only lead to the production of a greater quantity of products of combustion, without greater intensity. Where as much as 150 lbs. of fuel per hour were burned per foot of grate (as had been recorded in the "Sphinx" class of engine), it would matter little in the composition of the gases produced, or their relations to the receiving surface, whether or not the result was obtained by double the grate-surface with half the rate of combustion. He had no means of testing accurately the point at which the maximum rate of intensity was found; but as far as he had been able to observe, he thought that the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. li., p. 7.

greatest intensity was reached in locomotives with a combustion of about 60 lbs. of fuel per foot of grate. Beyond that point it did not matter whether much or little was burned. An engine, however, might start from London with a clean fire, having plenty of steam to spare for the first twenty miles, but by the time it reached Grantham or Leicester there would be clinkers all over the bars. The size of the grates was really determined by what was found necessary by that kind of mechanical inconvenience, and not so much by theoretical considerations. With reference to the nature of the distribution of heating surface, Mr. P. Stirling had lately popularised, by successful practice, the use of very small tubes in locomotives. In certain districts, however, it had been found that boilers with a similar size of tubes were comparatively useless, because the nature of the coal was such that they soon became coated with a tarry soot, which was a bad conductor of heat. Welsh coal, being for the most part free from smoke, did not possess that disadvantage; and the coal with which he had at the present time to deal was, he believed, in calorific value, not more than 10 per cent. below Welsh coal, but not more than half the amount of steam could be obtained from it, because it was impossible to avoid having the heating surface covered with a coating of soot. He was glad to find that reference had been made to the blast-pipe, apart from which the locomotive boiler ought not to be considered. He believed that no experiments made with a locomotive boiler, tried as a stationary boiler, with a uniform draught, were of the smallest value in estimating what it should do as a locomotive. It was natural to suppose—and the results of the practice of marine engineers confirmed it—that a boiler working with a steady suction draught would have an accumulating velocity in the current passing through the tube, so that when it got to the far end of the tube it would perhaps scarcely come in contact with it at all; and a long tube would here be of little value. But the draught in a locomotive was pulsating, intermittent, and he believed it was to that cause—the better impingement of the hot gases upon the tubes thereby produced—that the efficiency of a long tube in the locomotive was to be attributed. That was the reason why all such schemes as those proposed by the late Mr. Charles Wye Williams, for putting spiral distributors in the tubes, were of no value. About thirty years ago he was told by Mr. Crampton, that in experiments on the Great Western railway with some of the early engines, where two slide-boxes were on the top of the cylinders, and a plain T-pipe between them, the exhaust steam

from one cylinder crossed into the other to such extent as to produce a disturbance in the exhaust line of the indicator diagram, reaching, if he remembered rightly, nearly 40 lbs. per square inch. Considering how small an amount of favourable inclination of one pipe towards another was sufficient to prevent that back action, he had long been of opinion that concentric blast pipes in which one blast pipe might act as an exhauster for the other, the internal one acting sometimes on the outer one, and *vice versâ*, would be advantageous. Although it had not in his mind assumed much practical importance until lately, the extraordinary result obtained by Dr. Siemens' exhausters for the pneumatic despatch tubes, and by the exhausters used for the vacuum brakes, led him to think that it was possible that a large portion of the back pressure might be removed.

Mr. Bramwell believed Mr. Morton, the inventor of the ejector condenser, had applied that method to the locomotive engine.

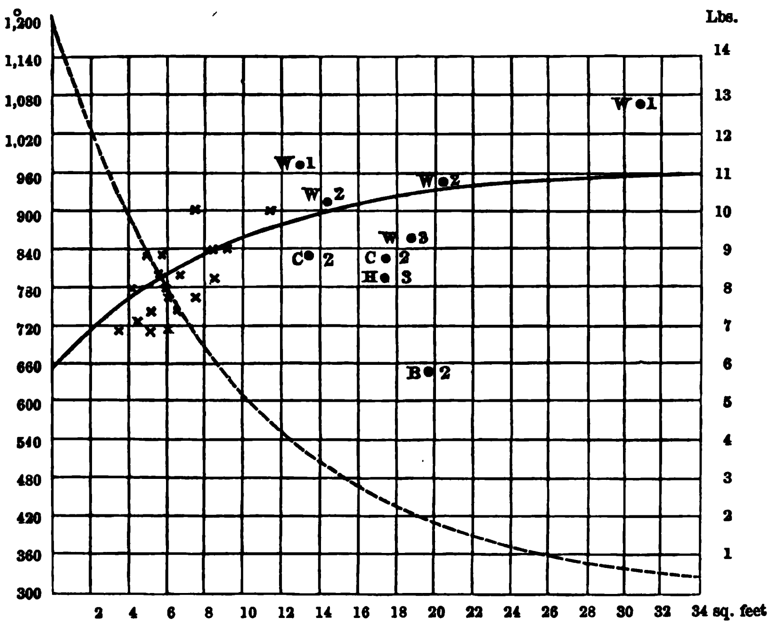
Mr. Phipps said the subject of the present Paper had always been interesting to him, since the first great change made in locomotive boilers by the introduction of the multi-tubular system in the "Rocket," an engine in the designs and construction of which he had taken part under the late Mr. R. Stephenson. One of the principal changes between the action of the multi-tubular system and the older system of boilers with flues of large sectional area (such as those for marine engines, and even the ordinary Cornish boiler) consisted in the rapid motion of the heated gases in the new system, to which circumstance, although perhaps erroneously, he had always attached importance. The consideration of this view led at once to the examination of the Author's assertion, that the diameter of a tube was a matter of indifference. As regarded the influence of rapid motion of heated matter through a pipe, there was a well-known difference in the amount of heat transmitted through a pipe in which steam was passing rapidly and that transmitted with steam of the same temperature at rest. With hot water instead of steam, he would expect some effect of the same kind, attributable to the necessity in this case, with the water comparatively at rest, of a considerable amount of molecular motion, in order to bring the heated particles in contact with the transmitting surface; in fact, this view involved the question, whether the heat might not be transmitted partly by conduction, as well as by radiation? In the case of the passage of steam above referred to, the slow transmission of heat was probably correctly attributed to the hindrance occasioned by condensation, forming a thin film of fluid

in the inside of the pipe. If, however, with heated air, the notion of speed of transit having anything to do with the rate of transmission of heat must be abandoned, and radiation alone was to be considered as the cause of transmission, there were then only the views of Mr. Z. Colburn to be considered as to the action of heat in tubes of different diameter. The view that the effect of radiation in tubes of different diameter might properly be compared to Newton's law of attraction, bringing out that the effect on any unit of surface of the tube was inversely as the square of the diameter, would also, when taken in connection with the quantity of heated matter, bring back the effect on each unit of surface to be simply as that surface. Referring now to the Author's contention that the length of tube had nothing whatever to do with economic effect, he thought the assertion required some modification, which observation also applied to the case of the diameter just considered, for it could hardly be said that if in some given case a boiler had been found deficient in evaporative power, this would not be improved by either adding to the length of the existing tubes, or otherwise, while leaving the tubes unaltered, increasing their diameter. He had been rather surprised at the statement that there was no difference in the rate of transmission of heat by different metals. Molesworth put it at—for copper, 898; for iron, 347. He had, however, been informed by the Author that Peclet, by careful experiment, had proved such to be the case.

Mr. SCHÖNHEYDER said empirical formulæ might be good as long as there were none better; but they were apt to mislead if used beyond the extent of the experiments from which they were derived. It had been shown in the Paper that Mr. Clark's formula for boilers applied exceedingly well to locomotive practice at one time, but that if used for exceptional cases it gave erroneous results. In dealing with surfaces for conveying heat from one liquid or gas to another, he had always taken into consideration the difference of the temperatures at the two sides; in constructing, for instance, surface condensers, feed-water heaters, &c.; and he had applied the same reasoning in designing boilers. Several years ago he had constructed for that purpose a curve (Fig. 4, p. 164), which was a slight modification of that shown in the Paper. The Author had taken the square foot of surface per lb. of coke to be burned, but he had taken the square foot of surface per cubic foot of water to be evaporated, because a boiler was not wanted to burn a certain quantity of fuel, but to evaporate a certain quantity of water in a given time. The Author's standard was like valuing a man by the wages he earned, instead

of by the work he did. A temperature of 2,400° was assumed for the furnace, and 1,200° for the initial temperature of the products of combustion entering the flues. This was considerably lower than was shown by the Author's diagram, because he did not believe that any portion of a boiler, not receiving the direct radiating heat of the furnace, could possibly be exposed to so high a temperature as had been assumed. As a proof of this

FIG. 4.



The abscissæ denote square feet of heating surface (exclusive of furnace) per cubic foot of water to be evaporated per hour.
The ordinates, to full curve, denote lbs. of water evaporated per lb. of fuel.
The ordinates, to dotted curve, denote temperature in flues, or tubes.

W.	Welsh coal.	1.	Galloway.	Experiments by Messrs.
H.	Hard steam coal.	2.	Cornish.	B. Donkin and Co.
C.	Coke.	3.	Lancashire.	Mr. Schönheyder.
B.	Breeze.	x.	Locomotive.	The Author.

he quoted some experiments by Mr. John Elder (recorded in the 'Artizan' for August, 1860) who found the temperatures in a boiler furnace from 3,200° to 3,610°, and immediately beyond the furnace (at the bridge) from 1,703° to 1,739.° For this reason the value of the heating-surface of the tubes, as given in the Paper, must be much too high. Had the furnace been lined throughout with fire-brick, the above assumed temperatures would have been

different. The dotted curve and the corresponding figures at the left of the diagram showed the reduction in temperature of the products of combustion as they passed along the flues, the loss of temperature having been taken (for equal surfaces passed over) in proportion to the difference of temperatures at the two sides of the plate; and the amount of surface per cubic foot of water to be evaporated per hour necessary to effect a given reduction of temperature having been fixed from the results of many experiments. The ordinates, measured to the full-line curve, showed the amount of evaporation which might be expected with a given surface, and were found by assuming that the loss of heat was in proportion to the temperature in the chimney. This, if not perfectly correct, he believed to be nearly so, and was according to Professor Rankine. To this was added a loss of 3 per cent. for ashes, and 5 per cent for radiation. Thus, for instance, with a little more than 10 square feet, exclusive of surface in the furnace, per cubic foot to be evaporated per hour, 600° might be expected in the chimney, or a loss of 25 per cent. of 2,400° = 600.° Added to this, 8 per cent. as above would give a total loss of 33 per cent.; so that if the full evaporative effect of coal was taken at 14 lbs. from 212°, and at 14·7 lbs. pressure, with 33 per cent. loss, it would be possible to evaporate 9⅓ lbs. of water per lb. of fuel, as indicated by the curve. The diagram was not put forward as infallible, but as a useful guide in determining the necessary surface for new boilers, or for comparing the work done by existing ones. Varying conditions, such as the state of the surfaces, sooty or clean, encrusted or not, amount of circulation, quantity of fuel, skill exercised in stoking, &c., would always cause practical results to vary from theoretical deductions. To show the extent of such variations, he had plotted the results of several experiments upon stationary boilers, as well as those given in the Paper for locomotives. The evaporative values for land-boilers were not those obtained at the trials, but those which would have been obtained, had the feed been 212,° and had the evaporation taken place at a pressure reckoned from a vacuum of 14·7 lbs. per square inch. The evaporation for locomotives was that given in column 21 of Table A, but he did not know the temperatures of the feed for those experiments. The surfaces taken in the calculations were, as for the stationary boilers, exclusive of surface in the furnace. From the approximation of these results to those indicated by the curve, he was of opinion that the evaporation in locomotive boilers depended upon the same laws as in stationary boilers, and did not,

for instance, depend upon such a factor as "surface ratio," *i.e.*, the ratio between heating and grate-surfaces. This was best shown with reference to that experiment with No. 1 boiler, which gave 12·8 lbs. evaporation, and in which the rate of combustion was only 3¼ lbs. per square foot of grate per hour, the surface ratio being only 22·6. He did not consider that the work which a boiler could do, either as to quantity evaporated from a given surface or from a certain amount of fuel, depended upon the proportion between the heating surface and the grate-surface. These parts had distinct duties to perform, viz., the heating surface to take up the heat developed by the fuel and impart it to the water, and the grate to effect the union between the combustible and the oxygen of the air. If only a poor draught existed, as in most stationary boilers, a large grate must be provided; but, if, on the other hand, there was not room for a large grate, as in locomotives, a powerful draught must be used; but the requisite heating surface for the same economical evaporation must be practically the same in either case. These remarks might seem somewhat elementary, but he thought it necessary to make them, as so much value seemed to be attached in the Paper to "surface ratios."

In referring to the co-efficient m, the rate of transmission of heat in units per hour per square foot of surface, and per degree of difference of temperature, which the Author had found from experiments by M. Havrez to be equal to about 11, Mr. Schönheyder remarked that with the temperatures on which his diagram was based, he had found it equal to about 8 for stationary boilers. He considered that a higher value would certainly obtain in locomotive boilers burning coke, on account of the cleaner surfaces, and possibly also, to a small extent, on account of the better conducting power of the materials used. He could not understand the Author's statement "that the evaporation from the box increases, whilst that from the tubes decreases, as m increases." It was contradictory to say that the higher the rate of transmission of heat the less would be the evaporation from the tubes. This was without any reference to the formula, which he had not examined.

Mr. Longridge, in replying, said there appeared to be a pretty general accord between his views and those of the various speakers. Mr. Woods seemed to agree with him that the important ratio was between the heating surface and the fuel consumed per hour. Of that he thought there could not be a doubt, judging either from experiment or from the results of analysis. His suggested

subdivision of the blast-pipe had not been derived from his formula. The formula was purely an empirical one, representing the results of his own experiments, and it was from the experiments themselves that he had come to the conclusion that great benefit would be derived from subdividing the jets. With regard to Mr. Clark's formula he had stated in the Paper that it had been derived with great care from a large number of observations; but at the same time it was purely empirical. He had shown that it would only apply under conditions similar to those of the experiments from which it had been derived. If, for instance, there was a ratio of heating surface to fire-grate as 300 to 1, and the fuel burnt was 100 lbs. per square foot per hour, there would be an evaporative effect of 23 lbs. of water to 1 lb. of coal, which would be double the actual amount. The object he had in view was to give a formula which would apply under all circumstances. He believed that his formula would be found generally applicable; but the constants were not yet determined with the degree of accuracy which he could desire. He believed that the 11 heat units per hour per square foot for each degree of difference of temperature was pretty nearly accurate, but he should be glad if experiments were made to determine the point, and also whether (as Mr. Bramwell had said) the difference varied with the temperature. He believed that it did vary with the temperature, but not to any great extent. He could not agree with Mr. Bramwell in his remarks respecting mechanical firing. His own experience had shown him that there was no necessity for it. If the boiler were well proportioned and admitted of a proper quantity of air above the bars as well as below, it did not matter whether one shovel full or twenty shovels full of coal were put on at a time. Sir William Armstrong, Dr. Richardson, and he had carried on extensive experiments with the old system of firing, putting on as much as 2 cwt. at a time, and they obtained the result of nearly 13 lbs. of water evaporated with 1 lb. of Newcastle Hartley coal, which was generally supposed to be inferior in evaporative power to the Welsh coal, though really it was not so. Mr. Reynolds had said the Paper was not one that would enable an engineer or locomotive builder to design a boiler; but, if he had looked at the Appendix, he would have seen an application of the formula to determine the dimensions of a boiler which should evaporate a given quantity of water with a given economical rate of evaporation. With regard to Mr. Reynolds' observations about the "Snake" and the "Iron Duke" class of engines, his formula showed that the latter would produce better economical results

than the former. The diagram represented, from actual experiments made some years ago, the whole result of water evaporated from different portions of a tube.

The table exhibited by Mr. Bramwell proved, in a striking manner, the need of such a formula as was given in the Paper. It had been maintained by Mr. Bramwell, and by other speakers, that in these days the art of designing boilers was so complete that no such formula would be of much use. Now if this were the case with respect to locomotive engineers, the knowledge did not appear to have been arrived at by agricultural engineers. In the table in question it appeared that the area of heating surface per lb. of coal burnt per hour varied from 1·93 square foot to 6 square feet, averaging 3·94 square feet, and in the prize engine it was in one experiment 5·37, and in another 5·50 square feet per lb. of coal. He had no hesitation in saying that such a proportion was abnormal. He had submitted this engine to calculation by the formula in the Paper, estimating the value of 0 from the analysis of the fuel given at p. 35, and the result showed that with a mean consumption of fuel of 40½ lbs. per hour, the evaporation would be:—

Fire-box	4·77	cubic feet per hour.
Tubes	2·95	" "
	7·72	" "
	= 482 lbs.	

which gave 11·90 lbs. of water per lb. of coal, the actually recorded quantity being 11·82 lbs. If in this engine the tubes, which were 6 feet long, had been reduced to 2 feet, the evaporation from the fire-box would have remained the same, whilst that from the tubes would only have been reduced from 2·95 to 2·89 cubic feet per hour. The total evaporation would then have been 7·66 cubic feet or 479 lbs., so that the only effect of the extra 4-feet length of tube was to evaporate 3 lbs. more water per hour, an increase of about 0·6 per cent. It was therefore evident that the designer of this prize engine, as well as those of most of the others, had very vague ideas about the proper proportion of heating surface.

Another remark called for by an inspection of this table was the strange latitude which appeared to have been allowed by the judges, with respect to altering the dimensions of the fire-grates when the engines were under trial. Surely if the proper size of a fire-grate for such an engine were 5·3 square feet,

it could not be right to reduce it to 3·2 square feet under trial. In other cases a grate of 4·3 square feet had been reduced to 1·6 square foot, and a grate of 7·2 square feet to 2·37 square feet. If these reduced grates were the proper grates for the engines, why had they not been so designed?

Mr. Longridge exhibited a model showing how a boiler would be carried upon three trucks so articulated that all the wheels might be driving wheels, and at the same time pass round curves with a small radius.

Mr. V. G. Bell remarked, through the Secretary, that the value of the Author's formulæ depended upon whether he was correct in assuming that the co-efficient *m* for the heat transmitted through the walls of the fire-box and tubes was, under all circumstances, a constant quantity. Experiments on the transmissive power of various substances, where the actual temperatures at the two surfaces were known, had shown that this power varied directly as the difference of temperature at the two surfaces, and inversely as the distance between those surfaces, and directly as some function of the density of the material. For a copper plate ½ inch thick, a transmissive power had been found about one hundred times the value which the Author had assigned to the co-efficient *m* in order to obtain from his formulæ results approximating to those obtained from actual experiment. He said, what was doubtless correct, that within practical limits the thickness and material of the fire-box walls did not affect the quantity of heat transmitted. The reason for these apparent anomalies was not, he thought, far to seek. The transmissive power of the gases themselves was small; consequently their temperature, where they were in contact with the walls, was low compared with that in the middle of the fire-box. The temperature of the gases in contact with the walls would vary nearly in inverse proportion to the transmissive power of the walls. Therefore, since the transmission varied directly as the difference of the temperature at the two surfaces of walls multiplied by their transmissive power, the actual heat transmitted from the fire to the water would be practically independent of the thickness and material of the plates. But it seemed inconceivable that the temperature of the gases at the walls should be the same at all points; it appeared reasonable to suppose that it would be highest where the gases first impinged, and lowest in remote corners where the motion of the gases was impeded. Hence he concluded that the form and dimensions of the fire-box would, to some extent, influence the value of the

heating surface. For similar reasons he questioned the absolute accuracy of the Author's conclusion that the value of the heating surface of the tubes was independent of their diameter. If, as he apprehended, the temperature of the gases was higher at the centre of the tube than at the circumference, small tubes should give a better result than large ones, more especially since the rate of flow must be greater at the centre than at the circumference.

Mr. WALTER R. BROWNE observed, through the Secretary, with reference to the Author's conclusions that the size and length of the tubes had absolutely no effect on the amount of water evaporated, that this was simply due to his previously eliminating the elements in which that effect would appear. This was evident from Appendix II. It was there said that if θ' be the temperature of the gases at η, and $\delta \theta'$ = loss of temperature in passing through $\delta \eta$, then $Q \sigma \delta \theta'$ = loss of heat of gases in passing through $\delta \eta$. This assumed that the temperature at any point of the gases was the same; but this would not generally be the case. The heat of the gases was communicated to the tube, not by radiation, as imagined by Mr. Zerah Colburn, but by conduction from the exterior surface of the gas, which was in contact with the tube; and it was only after this exterior surface was cooled that the heat would begin to pass from the interior. It might be argued that the gases were so agitated and mixed up in passing along the tube, that practically all parts of them were in contact with the tube surface for an equal time. This, however, was a matter to be proved, not assumed; and even if true of small tubes, as in locomotives, could not hold with large flues. Again, the speed at which the gases passed through the tube had nowhere been taken into consideration; but it evidently had an influence, since, supposing the speed infinite, there would be no heating of the tube, because there would be no time for conduction to take place. This consideration of speed was eliminated by taking for the quantity of heat transmitted to the water a similar expression $[n \pi d m (\theta' - T) \delta \eta]$ to that already employed for the fire-box. That expression could only apply where the quantity of heat was approximately stationary, which was the case with the fire-box, but not with the tubes. It was obvious on consideration, but was often overlooked, that the mere temperature of the gases inside any casing told nothing as to the quantity of heat transmitted through it, unless the speed at which the gases were moving was known. To this was probably due the discordance in the results obtained for m, as mentioned by the Author. Thus, if the speed were considerable, a long narrow

tube could not but absorb far more heat than a short and wide one of the same area; and hence in a locomotive boiler a number of long small tubes were a necessity, because the speed was high; while in a stationary boiler a single large flue was sufficient, because the speed was low. For these reasons he could not admit the Author's investigation as being complete from a theoretical point of view, though its results might be approximately correct within certain narrow limits.

Mr. LEWIS OLRICK stated, through the Secretary, that in dealing with the constants, the Author defined m as denoting "the units of heat transmitted from the gases inside to the water outside the tube per hour per square foot of surface for each degree of temperature." There could be no doubt that this was right, provided the tubes were surrounded with water; but in a locomotive boiler it was well known that the great majority of the top tubes were not surrounded with water, but with a bath of steam. This steam was the water evaporated from the lower rows of tubes, which, in ascending to the surface of the water, must of necessity envelop the top tubes in steam, and he had no doubt that this bath of steam would considerably deteriorate the power of evaporation of the top tubes. Even the lower tubes were dependent upon the degree of circulation of the water, and this had hardly received sufficient attention. The next point to which he would refer was the "ratio of heating surface to fire-grate." With reference to this, the Author said that the ratio was not between the absorbing surface and the fire-grate, but between the absorbing surface and the weight of fuel burnt per hour, and that upon this ratio the economical effect of any given boiler depended. With reference to this difference, he quite agreed, but there was a ratio of great importance which had not been referred to, viz., the proportion of coal burnt per hour to the calorimeter or area through the tubes. If this area was not in proper proportion, bad results would follow, and to prove this assertion he would refer to several instances from his own practice. Some years ago he had instructions to examine the boiler of the screw collier "Black Duck," which used an enormous amount of coal. The boiler had three grates, of 17 square feet each, giving a total grate-area of 51 square feet. The calorimeter, of two hundred and forty-three tubes each of 3¼ inches internal diameter, was 14 square feet. By calculation it ought to have been 11½ square feet only. He reduced it to 11·92 square feet by stopping up two vertical rows of tubes between each furnace, and the two lower horizontal rows of tubes immediately over the furnace crowns. By this reduction in the area of the

calorimeter the draught was much improved, and a saving was effected of 2 tons of coal per twenty-four hours, the reduction being from 13 to 11 tons. After this suggestion had been thoroughly proved by practice, the whole of the tubes were removed and the tube-holes plugged up, thereby adding considerably to the efficiency of the circulation in the boiler, and a further saving of fuel was effected. Several other steamers were altered in the same manner, with similar effects. From this experience it might fairly be inferred that the adoption of similar measures in locomotive boilers would lead to like results.

With respect to the "relative evaporative effects of fire-box and tube surfaces," although the Author denied that there was much difference between the efficiency of the fire-box heating surface and that of the tubes, he admitted that the average result was that 1 square foot of fire-box surface was equal to 2·61 square feet of tube surface. He believed, however, that this estimate was too low. To prove this he should have to refer to a somewhat different description of boiler. In doing so he knew it to be opposed to the ideas of locomotive engineers to advocate any other boiler, or even any other shaped boiler, for a locomotive than the old standard boiler; but more complete transformations than this had taken place in machinery without harm being done. On the contrary, great improvements had been the result. As the boiler to which he referred had been used for four road locomotives by the Indian Government, he considered it not without interest to the Institution that the result should be put on record. The boiler was known as the "Field" boiler, and its heating surface consisted of a fire-box, as in the locomotive. In addition it had the tubes suspended over the fire, thereby deriving the full benefit of the radiation of the heat from the flames, and in fact the whole of the tubes were surrounded by a bath of fire. This, in combination with the powerful circulation in the tubes (10 feet per second), caused by the arrangement of the double tubes, was no doubt the secret of its success. The external dimensions of the boilers were 7 feet 6 inches in height by 3 feet 3 inches diameter at the top, and 4 feet 3 inches at the bottom, having two hundred and eighteen tubes, with a heating surface of 127 square feet. There were 50 square feet of surface in the fire-box, making a total heating surface of 177 square feet. The evaporation, carefully tested by two independent engineers, was 48 cubic feet of water per hour, giving 3·68 square feet of heating surface per cubic foot of water per hour. This proved clearly that the efficiency of the fire-box heating surface was equal to 3·68 of the ordinary tube heat-

ing surface. The evaporation was 17 lbs. of water per square foot of heating surface, or a transmission of heat of 19,040 units per hour per square foot of heating surface. The weight of the boiler was only 2 tons, and as an ordinary locomotive boiler of that weight would only evaporate about 25 cubic feet of water per hour, it was evident that the "Field" boiler was far superior in evaporative efficiency. In India the boilers evaporated 2·87 to 3·12 lbs. of water per lb. of fuel, which latter was wet wood. As Welsh coal is to wet wood as 2½ and 3 to 1, the evaporation would have been from 6 lbs. to 8 lbs. of water per lb. of coal, but the boilers were designed for wood, not for coal, and had therefore a large grate-area and large combustion chamber. Mr. R. E. Crompton, the officer in charge of the steam train in India, had supplied the following table of the performance of the locomotive and of the "Field" boilers:—

—	Road steamer. Horizontal Locomotive Boiler.	Ranee. "Field" Vertical Boiler.	Road Steamer. Horizontal Locomotive Boiler with Wood.	Ranee. "Field" Vertical Boiler with Wood.
Weight of engine . .	7½ tons.	13 tons.	7½ tons.	13 tons.
Fuel used per ton per mile	3·05 lbs.	1·85 lb.	9·43 lbs. of wood.	4·57 lbs. of wood.
Water evaporated by 1 lb. of fuel . . .	4·3 lbs.	7·61 lbs.	1·4 lb.	2·87 lbs.
Speed per hour . .	4 miles.	9 miles.	4 miles.	9·6 miles.

Mr. Crompton also gave it as his opinion, after four years' experience, that the advantages of the "Field" boiler as compared with a locomotive boiler, for road steamers, were as follows: it occupied less space, the weight was less, it admitted of great variation of water level without impairing its efficiency; it was much easier to clean and to repair; and it kept up its efficiency with dirty water, the only kind available in India. It was impossible to get into and clean the ordinary locomotive boiler, the vertical tube boiler, and the pot boiler; but the "Field" boiler was sent into shed every fortnight and thoroughly examined and cleaned with very little trouble, and thereby the efficiency of the boiler was the same after four years' working as on the day it was started. Next, it could readily accommodate itself to work. At one time it could go up a steep incline, dragging a heavy load after it at 3 miles per hour, and at another time it would run 20 miles per

hour. When on a steep incline the tubes were never bared as in a locomotive boiler.

With regard to the blast pipe, the Author called it extravagant, but his experience pointed in a different direction. He would refer to some experiments made with a 10 HP. "Field" boiler, having 38 square feet of heating surface in the fire-box, and 100 square feet in the tubes. This boiler ought to evaporate 10 cubic feet of water per hour, but with the natural draught in the chimney and good coal, it evaporated 11·9 cubic feet of water per hour, and the economical value was 8·85 lbs. of water per lb. of coal. When the exhaust steam was turned into the chimney to act as a blast, the evaporation rose to 18·74 cubic feet, and as the economic value only fell to 8·37 lbs. of water per lb. of coal, he believed a good case had been made out that the blast-pipe was not extravagant. With reference to a number of small jets instead of one large central one, he had used this arrangement successfully for getting rid of the noise from the blast-pipe in busy thoroughfares; but the secret of the success was this, that the area of the outlet was considerably enlarged, and as the contraction of the blast-pipe increased the noise, so the enlargement of the area of the outlet lessened the noise. With regard to the greater efficiency of the blast-pipe, he believed it was owing, as stated, to the larger inlet, just as several safety valves were better than one of the same area, on account of the increased facility of outlet. To illustrate this an extreme example might be used. One valve of 10 square inches area would be $3\frac{5}{8}$ inches in diameter, and have a circumference of $11\frac{3}{8}$ inches. One valve of 1 square inch area would be $1\frac{1}{8}$ inch in diameter, and have a circumference of 3·53 inches. Now ten valves of 1 square inch each would be equal to 10 square inches, but the total circumference of the ten valves would be 35·3 inches, or three times as much as one valve of 10 square inches. With safety valves it was facility of outlet, in this case it was facility of inlet, and this, no doubt, accounted for the fact. The steam blast was a beautiful application of what was known as the "induced current." The "induced current" had received its name from the fact that a column of air, gas, or other fluid in motion, always had a tendency to draw into itself, and along with itself, atoms or particles of the fluid through which it moved. The theory of the "induced current" no doubt rested, first, on the fact that the atmospheric air pressed with an equal force in all directions. It consequently followed that wherever even a partial vacuum was created the atmospheric air would immediately force either air or other fluids into the vacuous space.

Secondly, the theory that all fluids consisted of minute atoms of a globular shape, and at equal distances, made it much easier to understand how the disturbance of a number of them by a forward motion of a column of fluid would act upon all the nearest in contact and carry them along with the currents; for as the column consisted of minute globes, similar to those of the fluid through which the column moved, the globes in motion, and the globes at rest were, so to say, intermingled in such a manner, being kept together by the atmospheric pressure, that it would be impossible for the column to proceed without either forcing the globes out of their places, or carrying them along. Those forced out of place, it must be recollected, would immediately be replaced by others, which, in their turn, would undergo the same process.

Mr. LONGRIDGE remarked, through the Secretary, that Mr. Walter R. Browne objected to the formula in Appendix II., because it did not fit in with an arbitrary assumption of his own, viz., that the heat of a body of air in a tube was diffused by conduction from particle to particle and not by radiation. This was a pure assumption, and could not be reconciled with facts. The conducting power of gases, such as those in the tubes, was so slow that if this theory were true, a thin film of cool air would pass along the surface of the tube, and the great body of the hot gases would reach the smoke-box so as to raise its temperature far beyond what was actually found in practice. The assertion that the speed of the gases affected the result was entirely erroneous, as might easily be seen by a careful consideration of the formula. With reference to Mr. Olrick's observations, he could not at all accept the conclusion drawn from the case of the "Black Duck." As stated, the case appeared to show, that by reducing the tube-surface in the proportion of 14 to 11·92, or by 15 per cent., the fuel was reduced from 13 to 11 tons. It was, therefore, concluded by Mr. Olrick that "the economy of the boiler was increased to that extent." But no such conclusion was legitimate. All it proved was that in the former case a larger quantity of heat passed up the chimney. No note was given of the quantity of water evaporated in either case. Another statement was evidently erroneous. It was said that the result of decreasing the flue-area was to increase the draught, a conclusion at variance with all experience, and in this instance shown to be erroneous by the diminution of fuel burnt, from 13 to 11 tons per day. This showed a decrease, and not an increase, of draft. It was also an error to state that the Author denied there was much difference between the efficiency of the tube and fire-box surfaces. On the contrary,

the Author showed that it varied from 1 to 1·7 up to 1 to 5·08. What he did say was, that so long as the total surface remained the same, the ratio between the tube and fire-box surfaces was of little consequence, as had been shown in Appendix V.

February 19, 1878.

WILLIAM HENRY BARLOW, F.R.S., Vice-President, in the Chair.

The discussion on the Paper No. 1,534, "On the Evaporative Power of Locomotive Boilers," by Mr. J. A. LONGRIDGE, occupied the entire evening.

February 26, 1878.

WILLIAM HENRY BARLOW, F.R.S., Vice-President, in the Chair.

No. 1,514.—"Liquid Fuels." By HARRISON AYDON.

LIQUID fuels comprise all classes of fluid hydrocarbons: the mineral hydrocarbons which are drawn from quarries, or from lakes, springs, or wells—as asphalt and bitumen; the oils which are obtained by the destructive distillation of coals and of bituminous shales and schists; and the animal and vegetable fats and oils which can be maintained in the liquid form at low temperatures.

Apparatus specially adapted for the combustion of liquid fuels, for the generation of heat for commercial purposes, may be divided into five classes. In the first class, liquid fuel is injected into the furnace, as spray, by the agency of compressed air, and is directed upon incandescent fuel. This process formed the subject of a patent, taken out in 1863 by Mr. W. Bridges Adams (Plate 3, Fig. 1). The Author is not aware that it was ever put into practice.

In the second class, liquid fuel, mixed with heated air, percolates upwards through a porous bed (Fig. 2). This was the system of Mr. C. J. Richardson, who patented it in 1864. It was tried at Woolwich Dockyard, but the performance was not satisfactory, for black smoke and soot were discharged in such abundance as speedily to choke the flue tubes and stifle the draught. According to a second patent of 1866, Mr. Richardson employed, with a greater degree of success, a mixture of steam and air, supplied through the porous bed, in conjunction with the liquid fuel. Messrs. Weir and Gay introduced an improved arrangement, shown in Fig. 3. In this class may also be included Sainte-Claire Deville's furnace (Fig. 14).

The third class comprised a preliminary process of vaporising the liquid fuel in a retort placed in the furnace, when it issued as gas through numerous jets. This was the system of Colonel Foote, of America (Fig. 4), and of that patented in 1865 by Messrs. Simm and Barff, of Glasgow.

In the next class the preliminary conversion of liquid fuel into

per lb. of fuel consumed. In these experiments, as in the first series, smoke was formed, with deposit of soot on the grate as well as in the flues. It may be added that the performance of coal, under the same boiler, amounted to an evaporation of 8 lbs. of water per lb. of coal. The results of the official trials are given in Tables[1] 1 and 2.

The third system of combustion, in which the liquid fuel is vaporised in a retort placed in the furnace and burned in jets, was tried in October, 1866, on board the screw yacht "Minnie," belonging to Mr. A. Barff. She was fitted with the retort apparatus at Millwall, and was the first vessel propelled by steam generated by liquid fuel. In these trials the oil was consumed at the rate of 3 gallons per hour, being 30 lbs. of oil as compared with 90 to 100 lbs. of coal, or 3 to 1 in favour of oil. The boiler was of 10 HP. with steam at 45 lbs. pressure. Although good results were obtained, the apparatus did not answer very well, as the retort was quickly burnt out, and required to be frequently renewed. It was afterwards tried with some modifications, under a patent taken out in 1867 (in which the use of steam was specified), in a small steamer fitted with a boiler with vertical water tubes, named the "Vaga," which was experimented with at Woolwich Dockyard, when an evaporation of about 12 lbs. of water was effected per lb. of liquid fuel. In this case, however, the heat generated was so great that the retort was melted, when this system became virtually the same as the fourth system, already referred to. On a subsequent trial the "Vaga" steamed twice round the Isle of Wight and to Portsmouth, where she was experimented on by the Admiral of the Port and other Dockyard authorities, who approved the performance of the boiler. In this as in the other case mentioned, it was found that by the addition of steam the intensity of combustion of the liquid fuel was materially increased, whilst smoke was entirely prevented.

In the fourth system, liquid fuel is injected into the furnace by steam, either plain or superheated, so as to convert the oil into vapour, and at the same time to mix it with just sufficient air to insure perfect combustion. The vapour, steam, and air in the requisite quantities are injected into the furnace (generally over the door), and there consumed. The combustion is perfect, the flame being lurid, transparent, and tinted with the brilliant colours

[1] *Vide* "Report of the Experiments that have been conducted at Woolwich Dockyard, with the view of testing the value of petroleum and shale oil as substitutes for coal in raising steam in marine boilers." P.P. 10th August, 1866.

of burning carbonic oxide and hydrogen; smoke is prevented, and the chimney need only be large enough to take off the waste products of combustion and carry them above the head of the attendant. As no draught is required, these products or waste gases may be allowed to escape at a temperature little above that of the steam in the boiler. No alteration of the ordinary furnace or grate is needed, so that either coal or oil can be used indifferently. For burning oil the grate bars are covered with thin fire slabs and a few cinders, and the ash-pit doors are closed, to keep out surplus air. A little carbon is occasionally deposited on the grate, where it remains in an incandescent state; but when the flame is doing duty properly, the ignited fuel, placed on the grate to inflame the vapour, is not burnt away.

In March 1867, this method of using liquid fuel was tried at the works of Messrs. J. C. and J. Field, South Lambeth, in a small Cornish boiler of 20 or 22 HP., 25 feet long, 5 feet 6 inches in diameter, with one internal flue 3 feet in diameter, in which the furnace was placed. The heating surface was about 100 square feet. The pressure of steam was 35 lbs. per square inch. The grate was not altered, but the bars were covered by a sheet-iron plate or by fire-bricks (on which ashes were laid), to close the openings between the bars; the ash pit was also filled with ashes, to exclude the entrance of air, as there was no door to the ash pit. According to a report of the trial, the plan is described as simple and effective, so far as the actual combustion of the oil is concerned, which is certainly perfectly free from any traces of smoke. The oil is allowed to run or fall through a small orifice, about $\frac{1}{8}$ inch in diameter, in a continuous stream at the rate of about 3 gallons per hour. As the oil falls vertically, it is met by a jet of superheated steam, which forces or blows the oil into the furnace in the form of a cloud of exceedingly fine spray, at the same time converting it into vapour, which then takes fire, and is consumed in a perfect manner. The quantity of water evaporated amounted to 10 cubic feet per hour, or 20·8 lbs. of water per 1 lb. of oil. The result of several days' experiments showed an average of 19·5 lbs. of water evaporated per 1 lb. of oil or liquid fuel. This boiler, with the best Aberdare coal as fuel, evaporated only 6·5 lbs. of water per lb. of coal, showing an advantage of 3 to 1 in favour of the liquid fuel.

The next trials of the fourth system were made with a double-flue Galloway boiler, 25 feet long, 6 feet in diameter, having a heating surface of 760 square feet, at the chemical works of Mr. Barnes at Hackney Wick. The ordinary coal-burning grates

were covered with loose bricks and ashes. The leading results of three successive experiments are given in Table 3.

TABLE 3.—RESULT of EVAPORATIVE PERFORMANCE of a 35-HP. GALLOWAY BOILER with LIQUID FUEL, on the 4TH SYSTEM, being a MIXTURE of FUEL, AIR, and JETS of STEAM.

No. of trial	1	2	3
Date of experiment	Feb. 21, 1868	Mar. 10, 1868	
Duration of trial . . . . . . hours	68	..	236
Oil consumed in twenty-four hours . gallons	250	240	230
" " per hour . . . . lbs.	104·1	100	95·8
" " per nominal HP. . lbs.	3·0	2·86	2·74
Temperature of feed-water . . . Fahr.	50°	..	..
Total quantity of water evaporated . gallons	11,050	..	51,456·25
" " " per hour cub. feet	26·74	..	33·33
" " " " . lbs.	1,672	..	2,080
Water evaporated per lb. of oil at 35 lbs. pressure . . . . lbs.	16	..	21·71
" " reduced for the temperature of 212° by Rankine's formula lbs.	19·4	20·30	26·0

Suppose the two oil-injectors, one to each furnace, consumed 35 lbs. of water per hour each, equivalent to 1 HP., making together 70 lbs. of water per hour, then a deduction equal to this amount in the third experiment would leave a net evaporative performance of 25·8 lbs. of water per lb. of fuel.

Experimental trials were also made upon another double-flue Galloway boiler, of smaller size, 25 feet long and 6 feet in diameter.

TABLE 4.—RESULTS of EVAPORATIVE PERFORMANCE of the SECOND GALLOWAY BOILER with LIQUID FUEL, on the 4TH SYSTEM, being a MIXTURE of FUEL, AIR, and JETS of STEAM.

No. of trial	1	2	3
Date of experiment	June 16, 1868	Feb. 8, 1872	Feb. 12, 1872
		h. m.	h. m.
Duration of trial . . . . . . hours	5	1·57	1·10
Oil consumed, total quantity . gallons	80	..	..
" " " . cubic feet	..	11	4·85
" " per hour . . lbs.	16	..	..
Temperature of feed-water . . . Fahr.	66°	46°	46°
Total quantity of water evaporated . gallons	1,524	..	..
" " " " cubic feet	..	94	58·54
" " " " per hour . gallons	304·8	..	..
Pressure of steam . lbs. per square inch	28	40	42
Water evaporated per lb. of fuel . . lbs.	19·05	8·69	12·06
" " reduced for the temperature of 212° by Rankine's formula . lbs.	22	10·37	14·4

In the second, third, and fourth trials much of the heat generated in this boiler was lost by passing up the chimney. An oven fixed in the flue at the throat of the chimney, for cooking the workmen's food, was kept constantly at a red and glowing heat.

The apparatus has now been at work on this and other boilers at the same establishment for the last nine years, and has given entire satisfaction. Before the apparatus for burning liquid fuel had been applied to the boilers, the works were invariably short of steam for some portion of the day, whereas afterwards there was always plenty of steam, frequently blowing off through the safety valves.

In the next example of the evaporative performance of the fourth system of burning liquid fuel, the trial lasted for seven entire days in March 1872. The quantity of oil consumed per hour amounted to 4·58 gallons. When more air was admitted by the breaking away of the fire-brick, or by negligence, the quantity of oil was raised to 6·67 gallons per hour. The boiler was of the common Cornish pattern, 30 feet long by 7 feet in diameter, with a 3-feet flue closed up at the front end by fire-brick, Fig. 8, thus forming a combustion chamber in which the oil was thoroughly gasified and inflamed before proceeding to the flues.

The coal consumed under this boiler in doing equal duty amounted to 280 lbs. per hour. If it be supposed that the evaporation was 6 lbs. of water per lb. of coal, then 280 lbs. $\times$ 24 $\times$ 6 lbs. = 40,320 lbs. of water evaporated per twenty-four hours by 3 tons of coal. If the largest quantity given of the oil be taken, viz., 160 gallons, to do the same work in twenty-four hours, then 1,600 lbs. of oil will be expended every twenty-four hours. Now 40,320 lbs. of water $\div$ 1,600 lbs. of oil = 25·2 lbs. of water evaporated at 35 lbs. pressure per 1 lb. of oil at a temperature of 50° Fahr., equivalent when reduced for 212° Fahr. to 28·9 lbs. of water per lb. of oil evaporated at atmospheric pressure. In this furnace much carbon was deposited, showing a want of air. The ratio of efficiency in favour of liquid fuel is as 4·2 to 1. A low evaporative duty of the boiler with coal has been taken; but it is perhaps quite as much as the fuel, which was slack, could effect. Experiments have been made with various other boilers, in which the evaporative duty ranged from 1½ to 1 to 3 to 1 in favour of liquid fuel.

Use of the Fourth System in Marine Boilers.

A boiler was fitted into steam launch No. 16 at Woolwich Dockyard, with a grate capable of burning coal, and also with apparatus

for consuming oil. From the report of the authorities the duty of this boiler with coal was equivalent to 8·5 lbs. of water per lb. of fuel from and at 212° Fahr.; but the steam jet into the chimney had to be kept constantly in action to maintain a sufficient pressure of steam to work the engines. The evaporative duty with liquid fuel from and at 212° was 12·33 lbs. of water per lb. of oil. During these experiments with liquid fuel the steam was kept up to 90 lbs. per square inch, with the feed on the steam constantly rising, and the engine running 150 to 160 revolutions per minute. The gauge generally showed 5 lbs. increase of pressure per minute. The combustion was described as perfect, with no smoke, the flame being a dull red and blue. The heat in the furnace was so intense that pumice stone melted like glass. The fault of this boiler was that it was much too short; it had a straight flue to the chimney, fitted with Field tubes (Plate 4). Before it was put into the launch, the Author found that the flame passed direct through the boiler up the chimney, and 8 or 10 feet beyond, keeping the chimney nearly at a white heat.

The results of these trials with the steam launch were considered satisfactory, and the Admiralty sanctioned the making of further experiments, on a larger scale, for which a boiler of the "Oberon," of 130 nominal HP., was ordered to be fitted up. This was done; but the boiler, having been used for other experiments, had been placed on the quay at the side of the Steam Basin of the Dockyard, one of the worst positions for obtaining the best results. The boiler was open on all sides, and exposed to the north-east winds blowing across the water. It was fitted with a superheater to each of the three furnaces, and had baffles placed in the uptake, so as to return the flame through the tubes. It had also a small auxiliary boiler fitted to supply steam to the injectors. From the report it appears that no attempt was made to ascertain the quantity of water that could be evaporated by liquid fuel, as the small boiler could not supply sufficient steam of the requisite pressure to burn the full quantity of oil; so that these trials seem to have been made to find out the best arrangement of furnace, the best size, form, and arrangement of injectors, and the quantity of steam necessary to inject and burn 1 lb. of oil.

At a trial on the 30th of November, 1868, the following results were obtained, viz.:—Total time of trial, three hours forty-two minutes. Pressure of steam in boiler, 20 lbs. per square inch. Temperature of the feed-water, 46° Fahr.; fire-room temperature, 62° Fahr. Total quantity of water evaporated, 20,286 lbs. Total oil consumed, 1,848 lbs. Then 20,286 lbs. of water ÷ 1,848 lbs.

of oil = 10·97 lbs. of water evaporated per lb. of liquid fuel, equal to 13 lbs. of water, if corrected for pressure and 212° Fahr. temperature.

At a trial on the 21st of April, 1869, which only lasted one hour four minutes, the following results were obtained:—Pressure of steam, 23 lbs. per square inch. Temperature of the feed-water, 56° Fahr.; temperature of the front of the boiler, which was exposed, 80° Fahr.; temperature of the uptake (gases heavy), 380° Fahr. Total quantity of water evaporated, 9,016 lbs. Total oil used, 624 lbs. Observed evaporation, 14·36 lbs. of water per lb. of liquid fuel. Evaporation corrected for pressure and temperature, 212° Fahr., 16·93 lbs. of water per lb. of oil. Calorific value of the oil (theoretic), 17·4 lbs. of water per lb. of oil. Loss in uptake, from 1·4 to 1·5.

Under the above circumstances it may be considered that good duty was obtained from the liquid fuel during the short time the trials lasted.

The results of other trials are given in Table 5 (see next page).

The trials with this boiler, and indeed all the trials made by the authorities at Woolwich Dockyard, must be considered a great mistake: for instead of having a proper steamer or gunboat fitted up and tried, the boilers experimented on were placed in the yard or at the edge of the water, for the most part unclothed and exposed to the cold winds and weather of winter, the workmen also having to be taught how to manipulate the apparatus. And yet, while labouring under all these disadvantages, good results were obtained, viz.: 14·22 lbs. of water evaporated per lb. of liquid fuel, with a temperature of the feed-water of 50° Fahr. This gives 16·77 lbs. of water per lb. of fuel, or 15·62 lbs. of water if the steam used by the injectors be taken into account.

Experiments were tried, in April 1868, on the river Clyde, when a small steam yacht of 15 tons burthen was fitted up under a patent taken out by Mr. Donald. This is a modification of the fourth system, and has been placed under the same head. The following is the report of the trial:—The voyage was from the Broomielaw to Greenock, exact observations of her performances being taken as far as Bowling. The distance was gone over in one hour fifteen minutes. The vessel was 44 feet long by 8 feet beam, and the speed obtained 8 miles per hour under a pressure of 32 lbs. of steam, with 175 revolutions of the screw. The quantity of oil used was 6 gallons per hour, or 60 lbs. per hour. The quantity of coal used to do the same duty was 224 lbs. per hour; and 224 lbs. of coal ÷ 60 lbs. of

TABLE 5.—RESULTS of TWO DAYS' TRIAL at WOOLWICH. "OBERON" BOILER, MULTITUBULAR MARINE.
Heating surface in tubes 1,468 square feet, in furnace and uptake 234 square feet; total 1,702 square feet; 130 nominal HP.

Date of Trial.	Time. Fires lighted in Trial Boiler.	Time. Steam up to 26 lbs. Pressure.	Time. Fire lighted in small Boiler for supplying Jet.	Time. Steam up to 20 lbs. in ditto.	Time. Commencement of Trial.	Time. Ending of Trial.	Time. Time occupied in Trial.	Temperature. Water in Boiler at lighting up.	Temperature. Temperature of the Feed-water.	Temperature. Atmosphere.	Temperature. Stoke-hole.	Temperature. Bottom of Funnel.	Fuel used for raising Steam. Small Boiler for Use of Jets.	Fuel used for raising Steam. Boiler for the Trial.	Weight of Oil used during the Trial.	Weight of Water evaporated during the Trial.	Water evaporated per 1 lb. of Oil consumed. At the Actual Temperature of the Feed.	Water evaporated per 1 lb. of Oil consumed. At the Constant Temperature of 100° Feed.	Water evaporated per 1 lb. of Oil consumed. At the Constant Temperature of 212° F. of Feed.
	A.M.	A.M.	A.M.	A.M.	P.M.	P.M.	H. M.	F. °	°	°	°	°			Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
1868 Nov. 13	9·25	10·20	8·0	9·0	1·17	4·25	3 8	160	50	54	66	120	Wood 5 lbs. Coal 60 lbs.	Creosote 260 lbs.	792·4	11,270	14·22	14·93	16·9
1869 July 1	9·25	9·05	8·0	9·05	12·40	5·02	4 22	144	62	70	..	Lead melts 640°	160 "	Coal 610 lbs. Oil 120 lbs. 730 lbs.	431·2	59,095	13·70	14·11	16·16

Date of Trial.	Cubic Feet of Water Evaporated per Hour. At the Actual Temperature.	Cubic Feet of Water Evaporated per Hour. At a Constant Temperature of 100° F.	Square Feet of Heating Surface per Cubic Foot of Water evaporated per Hour. Actual.	Weight of Oil consumed per Hour.	Weight of Oil consumed per Square Foot of Fire-grate Surface per Hour.	Mean Pressure of Steam Gauge.	Vacuum in Funnel.	Height of Barometer.	Description of Oil used during Trial.	Quantity of Soot.	State of the Tubes at the End of the Trial.	Description of Smoke.	Total Quantity of Water evaporated in the Small Boiler for the Use of the Jets.	Water evaporated in the Small Boiler per Hour for the Use of the Jets.		Useful Water evaporated, after deducting the Water used for the Jets to 1 lb. of Oil consumed. At the Actual Temperature.	Useful Water evaporated, after deducting the Water used for the Jets to 1 lb. of Oil consumed. At the Constant Temperature of 100° F.	Useful Water evaporated, after deducting the Water used for the Jets to 1 lb. of Oil consumed. At the Temperature of 212° F.
	Cubic ft.	Cubic ft.		Lbs.	Lbs.		Ins.						Lbs.	Lbs.	Cub. ft.	Lbs.	Lbs.	Lbs.
1868 Nov. 13	57·61	59·9	29·55	253	3·34	26	0·2	29·8	Country creosote	Very small	Slightly foul	Very moderate	774	247·2	3·95	13·24	13·76	15·62
1869 July 1	215·9	222·4	7·65	989	..	..	..	..	..	..	..	..	4,312	989·0	15·82	12·70	13·11	14·98

This boiler with best steam coal evaporated 8·4 lbs. of water per 1 lb. of fuel. The theoretic calorific value of the oil used was by chemical analysis 17·52 lbs. of water per lb. of oil.

oil = 3·7 as the ratio in this case in favour of the oil, as far as evaporative duty goes.

The fifth system was first tried in 1868, at the chemical works and tar distillery of the inventor at Deptford, at a great saving of expense and space in the purchase and storage of fuel. The ratio of evaporative duty in this case was as 2·5 to 1 in favour of the liquid fuel.

In October 1868 the steamer "Retriever," a screw vessel of about 90 nominal HP. and 500 tons burthen, was fitted with two vertical gas-generators. These, with their independent fires being placed on deck, were partly filled with creosote, obtained as a refuse product from the distillation of tar at the works, to be converted into gas by the independent fires. The gas so made was then conveyed to the three furnaces of the boiler below, where it was consumed as it issued from a series of jet burners $\frac{1}{10}$ inch in diameter. The fire-bars of these furnaces had been removed, and the ash pits were bricked halfway up. On this brick flooring a coil of piping, about 12 feet long by $1\frac{1}{2}$ inch in diameter, was laid in each furnace; and in these coils the perforations above mentioned were made, six in each furnace. The pressure of vapour in the generators was 35 lbs. per square inch, and the pressure of steam in the boiler of the engines was 15 lbs. per square inch, although steam of a pressure of 20 lbs. per square inch was raised in fifty minutes after lighting the vapour in the furnaces. The vacuum obtained was 25 lbs. per square inch. The number of revolutions of the engines was 58 per minute. Temperature of the feed-water, 108° Fahr. Consumption of liquid fuel, 35 gallons per hour, about 11·7 gallons per hour for each furnace, or 4·09 lbs. per HP. per hour. The weight of coal to do the same duty was 8 cwt. per hour, or about 10 lbs. per HP. per hour. The trial run was from Deptford to Thames Haven and back. There was an increase also of 1 knot per hour in the speed of the vessel in favour of the oil system.

On the 23rd of October another trial of this vessel was made. From the report of the trial the following particulars have been taken:—Time of trial, 12.25 P.M. to 5 P.M., or four hours thirty-five minutes. The quantity of oil consumed was = 230·1375 gallons, or, as the oil weighed 10·5 lbs. per gallon, = 2,416·44375 lbs. The average rate of consumption was 50·25 gallons, or 527·75 lbs. per hour, or 8·796 lbs. per minute. This is equal to 16·75 gallons per furnace per hour, and to 5·871 lbs. of oil per HP. per hour. The observed evaporation amounted to 450 gallons of water in thirty-six minutes, and this divided by

the number of lbs. of oil consumed in the same time gives the evaporative duty as $\left(\frac{4,500}{316 \cdot 5624}\right)$ 14·215 lbs. of water per lb. of liquid fuel. Correcting the observed evaporation to its equivalent evaporation for pressure and temperature (212° Fahr.), then it is found that 14·428 lbs. of water per lb. of liquid fuel = 12·356 lbs. of water at 60° Fahr., into steam at 212° Fahr. The temperature of the gases entering and leaving the chimney ranged from 482° to 622° Fahr., average 572° Fahr.; and as the temperature of the air was about 50° Fahr., the waste heat in the gases passing up the chimney corresponded to 522° Fahr. above the temperature of the air entering the furnaces for promoting the combustion. The report also states that during the trial there was very little smoke.

In enumerating the advantages of this process it will be seen that the results in favour of liquid fuel compared with coal are in the ratio of 2·5 to 2·7 to 1. Against this economy has to be placed the cost of the separate generators and their furnaces; also of a pump to force the oil into the generators, which must either be worked by hand, by a small engine, or by the large engine when in motion, and the extra fuel required to work the generators and pumps; for although these may be worked by the vapour generated after the first hour, yet the loss will be considerable, and must be taken into consideration in the account of the total quantity of liquid fuel used.

One of the disadvantages of burning liquid fuel by this system is the extreme danger arising from explosions and fire. The generators at times get red hot; at the same time they only generate sufficient gas for combustion. They are also liable to be clogged with solid carbon, of a similar kind to that found in gas retorts. It is this that causes the generators to get dangerously hot and liable to explode. This last disadvantage may be overcome by the introduction of a jet of steam into the generator, which immediately absorbs the carbon and prevents its deposition. But danger is incurred by the liability to explosion of the mixed gases. For instance, at the Millwall Ironworks, whilst the system was in course of trial without the introduction of steam, in a scrap furnace, the generator became red hot, and a cock attached thereto was either melted or blown out, when an intensely hot flame was projected across the works for 60 or 80 feet, setting fire to the roof and quickly dispersing the workmen. The apparatus was afterwards removed as dangerous.

Although liquid fuel may be burnt without the employment of

steam, yet it is consumed most economically and with the best results in the presence of steam; and of course the more highly superheated the steam, the better is the performance.

Liquid Fuel in Russia and other Countries.

In 1863–64 experiments were made in Russia in burning turpentine as fuel, on board a small steamer on the Neva. The results were fairly good, but the cost for fuel was excessive. However, advantage was taken of the successful experience in England in burning mineral oils, and the vessels of the Imperial navy on the Caspian Sea, and the steamers belonging to the Emperor of Russia on the Volga and the Neva, and many private steamers, have been fitted to burn liquid fuel. It is reported that all the other vessels of the Imperial navy of Russia are likewise to be fitted for burning liquid fuel. It was also tried in the locomotives of the Imperial railways of Russia, by Mr. Urquhart (Fig. 13).

In Germany, trials have been made of the fourth system in one of the naval dockyards.

In France experiments were conducted by M. Sainte-Claire Deville, on board steam vessels, and in locomotives (Fig. 14). In one of the latter on regular duty the quantity of petroleum consumed amounted to 14½ lbs. per mile run. On a brick slab or hearth streams of oil were allowed to flow from several pipes, the flow being regulated by means of a tap. The production of steam and the development of power were, it is reported, perfectly under control.

In America, in June 1866, experiments were made by Mr. Julius Adams, on Foote's system (Fig. 4), in burning crude oil in a stationary boiler 6 feet in diameter and 13 feet 6 inches in length, having an internal flue, with return tubes. The apparatus consisted of a combination of the third system with a portion of the fifth system. The vaporised mixture of liquid fuel and water was discharged into the furnace through ninety burners $\frac{1}{16}$ inch in diameter. The flame was vivid, intense, and free from smoke; and 34 lbs. of water were evaporated from and at 212° Fahr. per lb. of fuel. Trials were also made on board the gunboat "Palos" in Boston Harbour, about the year 1867, on a system designed by Colonel H. R. Foote, in which air and highly superheated steam were mixed with vaporised petroleum, the mixture issuing from one hundred and twenty-five jet burners arranged in each furnace. The performance was very good: but it is scarcely necessary to point to the liability to explosion of the heated mixture before

issuing from the burners. Chief Engineer Isherwood, of the U.S. navy, deduced from experiments on the utilisation of petroleum as fuel, that it yielded a maximum economy over the performance of the best anthracite of 68 per cent. by Fisher's method of burning oil; and of 38 per cent. by Foote's process of using liquid and solid fuel together; and he reports the failure of another method, on account of the obstruction of the tubes by the deposition of carbon. Other experiments were made by order of the U.S. Government by three of the chief engineers of the navy, who reported a calorific and evaporative power in favour of liquid fuel of 103 per cent.; and in the time of raising steam by oil as twenty-three minutes as against sixty minutes by coal, or 114·3 per cent. in favour of the oil. Mr. Isherwood also reports the advantages to be gained by the use of mineral oil, as follows:—

1. A reduction in the weight of fuel amounting to 40·5 per cent.

2. A reduction in the bulk of fuel of 36·5 per cent.

3. A reduction in the number of stokers in the proportion of 4 to 1.

4. Prompt kindling of fires, and consequently the early attainment of the maximum temperature of the furnace.

5. The fire can, at any moment, be extinguished instantly.

The above advantages have been pointed out long ago; yet there are others quite as important, viz.:—

6. Its capability of stowage in places where coal or other solid fuel could not be put, as, for example, in tanks in the bilge of a vessel, under the floors or between the skins of a vessel, as in vessels of war; or in the "Great Eastern," where it would act as ballast, water being introduced as the oil was used.

7. Its cleanliness, there being no smoke, no ashes, and no waste. With coal, the refuse, waste, or cinders varies from 7 to 16 per cent. of the fuel.

8. The prevention of the great loss of heat every time the furnace doors are opened to feed the furnace with coal, from a rush of cold air into the furnace.

9. In the ability to command a more intense fire and management of the temperature, without a forced draught, which, under some circumstances at sea, is of vital importance.

10. The facility with which perfect combustion may be secured, and the rapidity of raising steam.

11. Its being found in immense quantities, in almost every country throughout the world.

12. The advantage, both in a war-vessel and merchantman, of

there being no smoke, and therefore no black signal-flag showing the position of the steamer at sea, as is the case with the present steamers.

EMPLOYMENT OF LIQUID FUEL IN METALLURGICAL OPERATIONS.

With respect to the application of liquid fuel to scrap furnaces, experiments conducted by Mr. Churchill and Mr. Gouldy were made at the Millwall Ironworks. The oil furnace was an adaptation of an old furnace, 7 feet square and 2 feet 9 inches high, having a fire-grate 2 feet 6 inches wide and 7 feet long. It was filled with bricks, and acted as a combustion chamber. Three oil injectors played directly upon the metal to be heated, lengthwise of the furnace. These injectors were placed 12 inches above the hearth, but could be moved so as to point in any direction, and were connected with a superheating coil 35 feet long and 1½ inch in diameter.

On the 21st of August, 1871, the furnace having just been altered and in a green state, the fire was lighted and the oil turned on to dry and warm the furnace and to get it into proper condition for taking in the charges. On the 23rd, with the jets 12 inches above the hearth, fire was lighted in the furnace at 1.20 P.M., and the first charge was put in at from 4.5 P.M. to 4.13 P.M. The charge was 12 cwt., in six piles of 2 cwt. each: at 5.35 P.M. the first pile was taken out to be welded, but was not hot enough. At 6.13 to 6.19 P.M. the remaining piles came out at a welding heat, having only taken two hours' heating. Here work was stopped; the result being that in five hours 68 gallons of oil had been burnt, or 13·6 gallons per hour.

The time[1]	taken to heat	the furnace	with coal		was	six hours
„	„	„	by system	5	„	five hours
„	„	„	by „	4	„	two hours six minutes.

On the 24th the jets were lighted at 6.30 A.M., but owing to the attendants not being versed in the manipulation of the apparatus the furnace was not got into proper order until 10.55 A.M., when the furnace was charged with four piles of 2 cwt. each. At from 11.55 A.M. to 12.10 P.M., or in one hour fifteen minutes, the charge was withdrawn and welded. At 12.13 P.M. the furnace was again

[1] This time relates to the charge being put in to its being taken out at a welding heat.

charged with six piles of 2 cwt. each.[1] From 1.45 to 2.3 P.M., or in one hour ten minutes, the above charge of 12 cwt. of metal was withdrawn in good condition. At 2.30 P.M. other six piles of 2 cwt. each were placed in the furnace, and at from 4 to 4.15 P.M., or in one hour forty-five minutes, the whole of this charge of 12 cwt. was withdrawn in still better condition. At 4.30 P.M. the furnace was charged again with five piles of 2 cwt. each, and at from 5.25 to 5.35 P.M., or in one hour five minutes, this charge was withdrawn in excellent condition.

The furnace was at work altogether for eleven hours five minutes. The charges were in the furnace for five hours thirty-three minutes. The quantity of oil burnt was 140·5 gallons, 13 gallons per hour, equal to 130 lbs. per hour, or a total quantity for heating the charges worked off of about 722 lbs.

The following was the time taken, the weight of each charge, and the quantity of oil burnt per charge of metal and per cwt. of iron:—

	H. M.	Cwt.	Gallons of Oil used.	Gallons of Oil per Cwt. of Iron.
1st charge . .	1 15	8	16·67	2·08
2nd „ . .	1 28	12	18·87	1·57
3rd „ . .	1 45	12	22·94	1·77
4th „ . .	1 5	10	13·75	1·37
	5 33	42	72·23	

The time includes the drawing of the last pile of each charge, so that the average time would be less. During the third charge the furnace did not work well, but when the number of jets was reduced a great improvement took place, and during the last charge, there was, as will be seen by the table, a large reduction in the quantity of oil used.

In five hours thirty-two minutes, the total time occupied in making up, together with the intervals between, the charges, the quantity of oil consumed amounted to 68¼ gallons, being at the rate of 12½ gallons per hour.

	Cwt.	lbs.
Twenty-one piles of scraps of 2 cwt. each were put into the furnace, total weight	42	0
The weight of iron taken out was	37	20
Loss	4	92

being a loss at the rate of 2 cwt. 46 lbs. per ton, or 11½ per cent.

[1] At 12.53 P.M. the centre injector was turned off, when the fire was found to brighten at once, and give out a great increase of heat.

The yield of iron worked under the fifth system amounted to 35 cwt. 21 lbs. for a total charge of 42 cwt., showing a loss of 16½ per cent. The area of opening for the admission of air to the oil furnace when the best duty was obtained varied from 2½ to 3½ square inches for each injector. The furnace consumed 6,720 lbs. of coal in twelve hours to keep up the heat, against 1,405 lbs. of liquid fuel. The rate was thus 4·75 to 1 in favour of liquid fuel, the consumption of which was at the rate of 17 lbs. per cwt. of iron.

Loss of iron heated by coal		22 to 25 per cent.
" " " liquid fuel on system 4	11½	"
" " " " " system 5	16½	"

In 1875 the Author, at the invitation of several gentlemen interested in the development of the resources of the Dominion of Canada, proceeded there to experiment on reducing and smelting the refractory iron ores of that country. Many of these ores and iron sand are magnetic, and some of them contain 32 per cent. of titanic acid.

Operations were commenced at Marmora, in the county of Hastings, on the site of some old charcoal smelting works which had been abandoned for several years for want of fuel. Preliminary trials were made with a small reverberatory furnace, erected to test the effect of the liquid fuel in developing flame and heat. An old locomotive boiler was employed. Three jets being inserted at the back, as had been done at Millwall in England, with sheet-iron doors to regulate the amount of air required for combustion, the broken ore and limestone were put into the furnace through the arch from the top. The chimney was only sufficiently high to carry the hot gases above the heads of the workmen employed to put in the ore. After the furnace fire had been lighted and the oil turned on for two hours, the furnace was, from a green state, brought to a glowing white heat, and in about half an hour the first charge was put in through the hopper at the top. This charge consisted of 600 lbs. of refractory ore from the Toronto gold mine in a raw state, but the limestone used as a flux was burnt. This charge attained a white heat in about three-quarters of an hour, and in another half-hour began to melt. Two smaller charges were afterwards put in and melted, and the furnace set down. The next trial was with 1,500 lbs. of ore, besides flux, both in an unburnt state, composed of three different kinds of most refractory ore, so that a small quantity of red hematite was added, from a vein near the work, to aid in the fusion. In this trial the furnace became rapidly hot, the slag and metal running down in about two hours, and

everything proceeded in the most satisfactory manner for nearly twenty hours, when, from the intense heat of the burning oil, the fire-bricks were melted and the arch of the furnace was burnt. The metal was subsequently remelted and cast into pigs.

A cupola furnace was also built and tried; but although the charge about the hearth was melted, yet the flame could not be forced through the burthen in the body of the cupola by the pressure of the steam used in the injectors. It was found that oil fuel for this class of furnace must be used in connection with an air blast under pressure, all entrance of the atmosphere being cut off except through the tuyere. The sole object of these trials was to prove that the most refractory Canadian ores could be reduced and smelted by petroleum as fuel, with a view to introduce a new industry into Canada. About 15 gallons of petroleum per hour were, on the average, used in the experiments. The openings to admit air for combustion were 3 inches to 3½ inches square for each injector. The weather was so severe that the steam passing from the boiler to the furnace was condensed into water and actually frozen before it got to the cupola, at a distance of about 40 feet. There being no superheater at either the furnace or the cupola, the experiments had to be reluctantly closed for the season. As a welding heat could not be got by charcoal, and smith's coal was scarce, the smith's fire was fitted with an injector, when, with charcoal at the base of the fire, a welding heat was attained in a few minutes.[1]

The fifth system was tried at Woolwich Dockyard on a furnace for heating and bending boiler plates. The amount of oil consumed per day was 75 gallons of a specific gravity of 1·040 = 780 lbs., instead of 1 ton of coals to do the same duty. This gives $\frac{2{,}240 \text{ coal}}{780 \text{ oil}} =$ a ratio of 2·87 to 1 of efficiency in favour of liquid fuel. There was also a saving of time, the ½-inch plates taking with coal fifteen minutes to heat, but with liquid fuel only six minutes to arrive at the same heat, or as 2·5 to 1 in favour of oil.

A scrap or shingling furnace, the same from which the apparatus was removed as dangerous, was also fitted with the apparatus at the Millwall Ironworks, which did good service, the relative duty being as 1·5 to 1 in favour of oil.

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[1] Since the above was written, information has been received from Canada that further experiments have resulted in a complete success, the refractory and other ores having been smelted and reduced at a minimum cost by liquid fuel or native petroleum.—H. A.

The fourth system is still at work at Chatham Dockyard,[1] heating armour plates for bending, and has given great satisfaction to the authorities, who have observed a still more remarkable difference in the time of heating to that recorded of the plate furnace at Woolwich. Besides, the heat is reported to be remarkably even, and the iron free from scale, which is always noticed on iron heated by coal, and no difference of strength has been observed. The results of the experiments were 705 lbs. of liquid fuel (American petroleum), as against 31 cwt. of coal = 3,472 lbs., a ratio of 4·92 in favour of oil; but the production of smoke constituted an objection so serious as to discourage further effort. Since the time of that experiment, however, the above objection has been overcome, and the system has been applied to two armour-plate furnaces, the vapour generator being placed between, and supplying, both furnaces. Each furnace is heated by six jets of vapour, which enter at the sides, and through which openings the air to support combustion is also admitted. The jets play over the surface of the plate and the heat reverberates underneath. The liquid fuel consumed is 108 gallons per day for each furnace. The furnace in one experiment took one hour to get up heat, when an armour plate 7 feet 6 inches long by 3 feet wide by 6 inches thick was put in. This plate was withdrawn after a lapse of an hour and a half ready for bending. With coal this furnace took from four to five hours to get it thoroughly hot, and six hours further for heating the plate; one hour per inch of thickness of plate being the usual allowance, so that the time at the lowest estimate would be ten hours with coal against two hours and a half with liquid fuel. The saving in fuel was as 3·7 to 1, taking 3 tons of coal to be consumed during those ten hours. But the advantages do not stop here, for the nature of the fuel appears to have an important influence on the character of the iron, which is rendered cleaner and stronger. This is the case wherever liquid fuel is used in the manipulation of iron.

In 1875, while the Author was conducting the trials mentioned above, Dr. C. J. Eames was experimenting with a furnace for heating piles of scrap, for rolling iron into plates, by petroleum (Fig. 15). It is only a modification of Dorsett's system. The

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[1] Mr. W. Eames, Chief Engineer of Chatham Dockyard, in a note to the Secretary of the Inst. C.E., states that the use of creosote for heating armour-plates at Chatham Dockyard had been discontinued for some years on economical grounds, from two causes: first, the cost of the liquid had been increased to nearly double what it was originally; secondly, the liquor deteriorated in quality up to 50 per cent.—SEC. INST. C.E., March 17, 1878.

American patent was taken out in October, 1872, so that Dr. Eames had plenty of time to find out what Mr. Dorsett and others had done in England. The generator in this case is of wrought iron, similar to an egg-shaped boiler placed on end. It is divided by horizontal iron shelves, arranged alternately, projecting nearly across the generator. A fire in an independent furnace is placed under this generator, and in the fire there is a coil of pipes to act as a superheater to the steam, which is allowed to enter the generator at the bottom. The pipe supplying the petroleum is attached at the top, and on the oil-cock being opened, the oil runs on the top shelf, trickles across it, and falls on the shelf below, and so on for the other eight shelves in the generator. The oil in trickling from one plate to the other meets with the superheated steam, which has entered at the bottom, and immediately combines with it, and passes out of the top of the generator through a pipe with regulating valves into a combustion chamber. In this chamber it is further combined with air, before being allowed to enter the furnace through small orifices in the back of the furnace proper. The flame, after heating the charge in the furnace, passes under the boiler and then through an internal tube. This boiler supplies the steam required for the vapour generator and the steam hammer or rolls, as the case may be. The duty of this furnace is reported to be from 7 to 8 times in favour of liquid fuel as compared with coal. The quantity of crude oil used per hour by this furnace is stated to be 200 lbs., with a charge of 1 ton 5 cwt., or about 8 lbs. of oil per 112 lbs. of iron.

In a puddling furnace in which liquid fuel was used, forty minutes were occupied in getting up the heat, and each charge of 500 lbs. was converted in forty-five minutes by 61 lbs. of petroleum, or 273 lbs. per ton of metal converted against 1½ ton of coal, or as 12 to 1 in favour of liquid fuel.

In a balling furnace with coal the time of getting up the heat was from seven to eight hours, after which four heats per hour were obtained. With petroleum heat was got up in from thirty-five to forty minutes, with six heats afterwards per hour; the produce of each heat of 175 lbs. is equal to 1,050 lbs. of iron per hour. The consumption of oil per hour is 12 gallons.

This communication is accompanied by a series of small scale drawings, from which Plate 3 has been compiled.

[APPENDIX.

APPENDIX.

LIST OF PAPERS ON THE SUBJECT OF LIQUID FUELS IN DIFFERENT PERIODICALS, ETC.

1865. Adams, Col. Julius W. Report to the Trustees of the Petroleum Light Company, of Experiments made at the Morgan Iron Works, New York, on Petroleum as Fuel.

Gesner, A., M.D. A Practical Treatise on Coal, Petroleum, and other Distilled Oils. 8vo. Plates and Cuts. New York, 1865.

Richardson, C. J. Petroleum as Steam Fuel. Journal of the Royal United Service Institution. Vol. ix. p. 70.

Selwyn, Capt. J. H., R.N. Petroleum as Steam Fuel. Journal of the Royal United Service Institution. Vol. ix. p. 62.

1866. Parliamentary Paper, No. 503. Petroleum and Shale Oil. Copy of a Report of the Experiments that have been conducted at Woolwich Dockyard, with the view of testing the value of petroleum and shale oil as substitutes for coal in raising steam in marine boilers. 10th August, 1866.

1867. Rankine, W. J. M. On the Economy of Fuel, comprising Mineral Oils. Journal of the Royal United Service Institution. Vol. xi. p. 218.

1868. Dorsett, G. Liquid Fuel. Dorsett's patent apparatus for applying it to steam boilers and furnaces generally. Tract, 8vo. Vol. clxiv. London, 1868.

Paul, B. H. On Liquid Fuel. Journal of the Society of Arts. Vol. xvi. p. 400.

Selwyn, Capt. J. H., R.N. On Liquid Fuel. Transactions of the Institution of Naval Architects. Vol. ix. p. 88.

Selwyn, Capt. J. H., R.N. Further Information on the Employment of Mineral Oils as Fuel for Steamships. Journal of the Royal United Service Institution. Vol. xii. p. 28.

1869. Selwyn, Capt. J. H., R.N. On the Progress of Liquid Fuel. Transactions of the Institution of Naval Architects. Vol. x. p. 32.

Sainte-Claire Deville, H. Mémoire sur les Propriétés physiques et le Pouvoir calorifique des Pétroles et des Huiles minérales. Comptes-rendus des Séances de l'Académie des Sciences. Paris. Vol. lxviii. pp. 349, 485, and 686.

Sainte-Claire Deville, H., and Dieudonné, C. De l'Emploi industriel des Huiles minérales pour le Chauffage des Machines, et en particulier des Machines locomotives. Comptes-rendus des Séances de l'Académie des Sciences. Paris. Vol. lxix. p. 933.

1870. Selwyn, Capt. J. H., R.N. On Liquid or Concentrated Fuel. Transactions of the Institution of Naval Architects. Vol. xi. p. 160.

Selwyn, Capt. J. H., R.N. On Liquid or Concentrated Fuel. Journal of the Society of Arts. Vol. xviii. p. 543.

Also Dr. Paul's Report of the Trial of the S.S. "Retriever."
Professor Henry Wortz's Reports on Eames' Petroleum Furnace.
Professor Thurston's Investigations.
Dr. Antill's Treatise on Shales, &c.

[Mr. Lewis Olrick

Mr. Lewis Olrick said the question of liquid fuels was one with which he had had some experience, and he thought it might be interesting to direct attention to diagrams taken from the working drawings of a boiler executed by order of the Government, and fitted with liquid fuel. Figs. 1, 2, and 3, Plate 4, represented a small "Field" boiler made to replace another tubular boiler taken out of an official launch, No. 16, belonging to the Chief Constructor at Woolwich, so that it was necessary to make it of the same external dimensions. It was necessary to fit two pairs of engines, one on each side of the boiler, exactly to the foundation in the ship; the peculiar construction, therefore, was no fault of his. The Author had stated that the boiler was too short, but that was a simple matter of necessity. Fig. 1 was a cross section of the boiler. Fig. 2 was a longitudinal section showing the injector, the superheater, the first bridge, the deflector, the second bridge, and the means of inlet to the chimney; this arrangement was to give the gases the longest course, so that they might part with more heat than would be possible if there was a straight passage to the chimney. Fig. 3 was an end view showing the oil tank and the piping carrying steam from the boiler, and oil from the tank to the injector; also by dotted lines an end view of the superheater. Fig. 4 was a section of the injector. The injector had one entrance for the steam, and one for the oil; but the entrances could be varied if necessary, the central cone carrying the steam and the annular space the oil, or *vice versâ*. This arrangement of injector had been adopted in a number of instances, and had worked satisfactorily. The superheater served to heat the steam considerably above the ordinary temperature corresponding to the pressure of the steam, and in many instances better results were obtained when the steam was superheated. The reason, he believed, was that some of the hydrogen was utilised that could not otherwise be burned. As soon as the injector was started, by putting on a handful of shavings so as always to have a flame to begin with, the flame ascended over the first bridge, or amongst the tubes; the deflector then compelled it to go down again, next it rose over the second bridge, and finally reached the entrance at the bottom of the chimney, or through the small annular space at the top. The boiler was tested to 250 lbs., and worked at a pressure of 180 lbs. It drove two pairs of engines, with 4½-inch cylinders, at one hundred and sixty revolutions per minute, under a pressure of 90 lbs. The heating surface in the fire-box was 45 square feet, and in the "Field" tubes 82 feet, making a total

of 127 square feet. With coal the mean evaporation, in a trial of seven hours, was 7·1 lbs. of water per lb. of fuel, the engines making one hundred and fifty revolutions per minute under 90 lbs. pressure of steam. With oil the evaporation rose during the same number of hours to 10·2 lbs. per lb. of fuel, making the same number of revolutions under the same pressure, showing an increased efficiency of 44 per cent.

Figs. 5, 6, 7, and 8, Plate 4, represented a double-flued Cornish boiler fitted with Mr. Aydon's apparatus for burning liquid fuel. The boiler was 30 feet long and 7 feet in diameter, and had two flues each of 7 feet 6 inches in diameter. It belonged to Mr. Duncan, and was used at a sugar refinery at Lavenham. Fig. 5 was a cross section showing the superheater. Fig. 6 was a sectional plan showing the superheater and external arrangement of the injector and piping. Fig. 7 was an end view showing the arrangement by which the steam could either be taken direct from the boiler, or be allowed to pass through the superheater before reaching the injector. Fig. 8 was a longitudinal section showing the position of the injector, and a section of the superheater. The mode of fitting it was of the simplest description, and heated the steam to a temperature of 600°, the ordinary temperature of the steam being 307°. The steam-pipe took the steam first direct from the boiler into the injector without passing the superheater. The main oil-pipe led from the tank to the boiler. When the steam was afterwards made to pass through the superheater, better results were obtained than with the steam taken direct from the boiler. The plan of leaving the fire-bars in the usual way was very convenient, because it was necessary to get up steam with coals, and then the liquid fluid apparatus could be used. All the ashes were left on the fire-bars, and if there was flame enough, oil was simply turned on by a jet of steam; if there was not enough, it was necessary to produce it before the apparatus could be started. On one occasion the apparatus was reported to be very dangerous; but the fact was the rule laid down had not been followed, viz., that when the apparatus was to be started, it was necessary that a flame should be kindled by lighting one or two handfuls of shavings and then putting oil on them. It appeared that after the dinner hour the apparatus was started by merely squirting the oil on the ashes that were nearly extinct, the consequence was that gas formed, and, suddenly igniting, an explosion took place.

With regard to the question of economy, when liquid fuel was about ½*d*. per gallon, the efficiency was from three to five times that

of coal. That was the original price of the heavy oil, the refuse from tar distillery; but when Government began to use it, the price was increased to such an extent that what was gained in efficiency was lost in price. The weight of the oil was about 65 lbs. per cubic foot. There could be no doubt, however, that, both in the Royal Navy and in the mercantile marine, even if the price of the oil were the same as that of coal, the advantage of using it would be very great. A much larger supply of fuel could be kept on board, in hot climates the stokers would not suffer as they did at present, and the same-sized boiler could be made to give double or treble the amount of steam.

Admiral SELWYN said he had often drawn attention to this subject, which appeared to him to be one of the utmost importance, involving not only an economy of fuel for steam purposes, but a condensation of fuel. In steamers, particularly in the Royal Navy, the question of the quantity of fuel that could be carried was of the greatest importance, as efficient sails had been entirely given up. No steamer in the British Navy could carry more coal than was required for three days' full steam. No doubt a steamer could go at a slow speed for a greater number of days by using an expansion arrangement; but three days was the limit of consumption at full power. If the enemy was going at 15 knots an hour, it would not do for her pursuer to go more slowly. The system described in the Paper would, according to all trials that he had made and seen, at least give nine days' consumption instead of three. The system was also of importance, as teaching for the first time that fuel could be burnt so as to produce the full calorific value assigned to it by chemists. He desired to refer shortly to a Paper he had written on the subject for another Institution. In the trials at Woolwich Dockyard, made under his superintendence, it was first ascertained from the chemists that, according to the chemical composition, the fuel was capable of evaporating 17½ lbs. of water by each lb. of oil; and the amount actually evaporated was 16·1 lbs. There was a loss of 2·7 units of heat up the chimney; so that apparently 18·8 units of heat were produced, instead of 17·5. How was the excess obtained? Unmistakably, because the hydrogen of the steam was burned; and it was to that point that he desired to draw attention. Bunsen and Fyfe stated[1]: "Red-hot coal and aqueous vapour mutually decomposed each other into hydrogen and carbonic-oxide gases, with some carbonic acid, both of which, if sufficient oxygen be present,

[1] *Vide* Transactions of the Institution of Naval Architects, 1870, p. 161.

burn with the production of a white heat to form water and carbonic acid; numerous observations showed further that the additional heat evolved more than compensated for the fuel used in producing the vapour." His own experiments corroborated that fact. The instant the temperature of the steam was raised by superheating before uniting it with the oil, it was found that the hydrogen of the steam was more perfectly burnt; and the higher the pressure of the steam the better it combined with the oil, and the better the hydrogen of the steam burnt; so that if a proper heat could be got in the furnace by the use of fire-brick chambers, it might be hoped to burn the whole of the steam used for blowing in the oil. "If the hydrogen had been perfectly burnt in my experiments, and the quantity of hydrogen present in the steam had been only that due to the 1 lb. of water (equal to 1 lb. of steam) which was used per lb. of fuel to blow in the hydrocarbon oil, we should, on this account, have to add to the calorific effect obtainable from the fuel, as above, viz., 17·5 lbs., a further quantity of 7·062 lbs. obtainable from the perfect combustion of the hydrogen in the steam; and if in the boiler used there was no loss of heat up the chimney, and the theoretical result had been realised, a total evaporation of 24·562 lbs. of water per lb. of fuel and steam would have been obtained. Again, if a higher class of hydrocarbon had been used, such as is common enough, with a calorific value of 22 instead of 17·5, our total evaporative effect would have been 29, or four times as much as we get with badly burnt coal."[1] In many of the experiments in England, America, and elsewhere, the extraordinary results obtained were due to the fact that the heat of the combustion chamber was very great. "The highest calorific value obtainable from liquid hydrocarbons appears to be that derived from the 'sextane' of Hofmann, the composition of which is C. 72 per cent., H. 28 per cent., but this is not to be had in commercial quantities. Its calorific value is 28·72."[1] "The heat of burning hydrogen is 5,775° Fahr. No such heat was ever obtained during the Woolwich experiments, but it was obtained at Messrs. Griffiths' factory, Victoria Park, and there, in a proper fire-brick combustion-chamber, built inside the boiler, 160 gallons of oil per day did the work of 3 tons of coal, or an evaporative effect of 46 lbs. of water was obtained by the use of 1 lb. of fuel plus 1 lb. of steam."[1] At the trial he was at a loss to account for the result. He tried the chemical composition of the oil, and found that the

[1] *Vide* Journal of the Royal United Service Institution, vol. xxi. p. 119.

quantity of water theoretically to be vaporised was 21 or 22 lbs.; taking the hydrogen in the steam, he obtained about 7 lbs. more. How was the difference to be accounted for? "Recent chemical experiments have shown that decomposition of water takes place whenever steam is passed over heated coke or carbon. Hydrogen, carbonic oxide, and carbonic acid are produced. The analysis of the gas obtained by passing steam over red-hot charcoal for some hours gave as a mean—carbonic acid, 20 per cent.; carbonic oxide, 20 per cent.; hydrogen, 60 per cent. If metal, such as iron, be present, it adds to the quantity of hydrogen according to another action, in which there is a combination with the iron, and this mixture of gases is inflammable, and burns with a non-luminous but hot flame, the heat of which would be increased if the carbonic acid were previously removed." Thus it appeared that, so far as the chemical question was concerned, it was perfectly possible to produce and burn with good effect the combustible gases contained in water-vapour under certain conditions, not in themselves difficult of fulfilment; the first thing was a sufficiently hot chamber, the second the presence of carbon in any of its forms, and the third the presence of iron or some such metal. Now, for the effect to be expected which was to induce a trial of the experiment. If 60 per cent. of every lb. of steam blown in with, and used to blow in, the hydrocarbon were hydrogen with 20 per cent. carbonic oxide and 20 per cent. carbonic acid, a proportion of 80 per cent. was rendered combustible; even without the presence of iron this should give more than 48 units of heat, 38 being due to the hydrogen alone, and 10½ to the carbonic oxide. Those observations showed how imperfectly fuel was now burned. The experiments had not been continued, partly on account of the cupidity of those who had run up the price of the dead oil used. There was, however, an unlimited supply of it. It could be obtained from the blue shale at Poole, in Dorsetshire, at the rate of 40 gallons per ton, and there was no doubt that when its full value was understood, both for metallurgical purposes and for the use of shipping, the subject would again receive attention. He did not think that any better plans of burning would be found than those already adopted. He congratulated the Author on the result of his working. He had been of late years connected with mines, and one of the chief difficulties experienced in the reduction of metals had been the introduction with the fuel of a great many things that were not desired. In smelting ores engineers would be glad to resort to something like oil, which was a perfectly pure

fuel. The metallurgical question had come, to a certain extent, under his notice in the Woolwich experiments. The ordinary bolts of iron in the pieces of wood used to light the fire with came out with all the qualities of the best Swedish iron; they were diminished considerably in size, but they came out perfectly fit for making harpoon iron. Some metallurgists were now using the system for all their crucibles, and they were able to deal with platinum by the heat obtainable from liquid fuel as they formerly dealt with lead. For that and for many other purposes he believed liquid fuel would be employed, and he hoped the experiments of the Author and of others would be carried on until the importance of the subject was universally recognised.

Dr. PAUL said the attention he had been able to give to the subject had led him to an opinion entirely unfavourable to the use of liquid fuel as a substitute for the ordinary materials. With regard to petroleum, which was found in America, in the east of Europe, round the Caspian, and elsewhere to a considerable extent, the principal objection to its use was the extreme volatility of a very large portion of it. From 30 to 40 per cent. of the American petroleum was capable of assuming a gaseous form at the ordinary temperature of the atmosphere, and that vaporised portion, when mixed with air, formed a gas as explosive as ordinary coal-gas under similar circumstances. The use of such a material would be extremely undesirable under conditions such as obtained in the stoke-hole of a vessel. The next objection to it was the cost. At present it was exceedingly cheap, about 6*d.* per gallon, representing 8½ or 9 lbs., or from £5 to £6 per ton. The calorific power of average petroleum was about one-third more than that of steam coal. Another objection to the use of natural oils was the small quantity available for the purpose. The quantity raised in America did not exceed 600,000 tons a year, which was altogether insignificant for the supply of either the mercantile or naval marine. With reference to the artificial oil obtainable by distilling coal or shale, he believed there were few shales that would yield as much as 40 gallons per ton, but even at that rate it would be very costly. To obtain 3 cwt. of the oil a ton of the raw material would be required, and how would that have to be dealt with? It would have to be put into retorts, and fuel would have to be consumed to distil the oil out of it, and that would go far to neutralise any advantage which the oil might possess as fuel when compared, for instance, with Aberdare coal. With regard to the volatility and the obtainable quantity, the objections were not so strong as they were against petroleum; but the oil

contained a large proportion of easily volatilisable material which would form an explosive mixture with air. The dead oil or creosote certainly presented great recommendations for use as fuel. It was exceedingly dense, weighing from 11½ to 12 lbs. per gallon. In case of accident this oil would sink instead of floating and taking fire as petroleum or shale oil would do. It burned readily, and was cheap, but the quantity to be obtained was small. There were circumstances under which the use of the material was advantageous, but they differed from the circumstances under which the fuel was used in the Navy. To a tar distiller the oil was a nuisance, and of course it would be a great advantage to him to use it as fuel, but that afforded no argument for introducing it into steam vessels. No doubt it was very cheap, about ½*d.* per gallon, but as soon as there came to be a demand for it the price would of course be increased. There was one use of liquid fuel in the heating furnaces for bending boiler plates which seemed to promise considerable success. The advantage there was that a highly carburetted atmosphere was obtained in the furnace, and none of the cutting or oxidation of the surface was brought about that was often so prejudicial in the working of iron plates. He believed that at Woolwich Arsenal and elsewhere that mode of bending boiler plates and armour plates had been found advantageous. He was glad to find that the statements made with regard to the use of liquid fuel were of a much less immoderate character than they were twelve or fourteen years ago, when it was said that 1 ton of liquid fuel was equal to 5 or 6 tons of coal. With reference to the advantages to be gained by the burning of steam, he was surprised that Admiral Selwyn had not yet divested his mind of that phantasm. If he was still following out that idea, why did he not go further, and, instead of expending heat in producing steam, use a jet of water and burn it at once? It had always appeared to him that the use of liquid fuel had all the defects of a half-measure, missing many of the advantages of solid fuel, and falling short of the signal benefits realised by the use of fuel in a gaseous form. That appeared to be the most natural and scientific mode of applying fuel, because, however coal or wood, or peat, or even liquid fuel was burned in a furnace, the first effect was the conversion of a considerable portion of the material into gas. Some of the greatest advances made in the use of fuel had been secured by the ingenious applications of Dr. Siemens for applying fuel in the gaseous form to the various purposes required.

Mr. E. F. BAMBER remarked that the greatest portion of the loss in a steam engine did not take place in the furnace. In the best regulated furnaces with draught only about one-fifth was lost. According to a statement in the Paper, that would be reduced to one-tenth; but when that one-tenth was multiplied by the ratio of the difference between the temperature of condensation and the temperature to which the steam was raised in the boiler, to this latter temperature on the absolute scale, it came out eventually that there was only about one-fortieth in favour of liquid fuel. With regard to the cost, he was surprised at the statements that had been made. At 1½*d.* per gallon, liquid fuel would be about the price of coal; but at 6*d.* a gallon it would, of course, be much more expensive. For smelting and metallurgical purposes, the use of liquid fuel was important. It had been stated that 1 ton of iron was heated with 35 cwt. of coal in an ordinary furnace, and by about one-fourth of that amount when liquid fuel was used, which was, of course, an enormous advantage. But in economical furnaces, such as the Regenerative Gas furnace, 1 ton of metal would be re-heated with 17 cwt. of coal; and when the price of coal was taken into consideration, the advantage was greatly on its side. Reference had been made to the production of heat from substances which had already entered into combustion. It was surely a well known fact that in steam the hydrogen was already burned, and if it were reproduced, as much heat must be used as it gave up. The economical application of steam was in decomposing it by heat which would otherwise be lost in radiation, as in the Regenerative Gas furnace, underneath the hearth of the producer of which a slight amount of water was put, and the heat which otherwise would be wasted decomposed the water into its constituents hydrogen and oxygen, thereby enriching the produced gas. But the idea of turning water into fuel with advantage, except with waste energy, was one which he could not accept.

Admiral SELWYN said that the words he had quoted on that subject were not his own, but those of Professor Bunsen and Mr. Fyfe.

Mr. CRAMPTON thought it desirable to keep as nearly as possible to actual practice. No one could expect to get more out of a thing than there was in it. There was unquestionably great value in liquid fuel. Liquid fuels would not evaporate, theoretically, more than 17 or 18 lbs. of water. Coal theoretically evaporated 13 or 14 lbs.; the difference, therefore, was as 13 to 18, and no more; and if the price of liquid fuel was proportionately higher, it was clear that

in that respect there was no advantage attending it. As to burning water, no one could believe that more could be got out of water after it was vaporised or decomposed than there was in the heat used to vaporise or decompose it. If anything could be done with water, why should it not be used direct, so as to save fuel altogether? In examining questions of that kind, it was desirable to keep as far as possible to the evaporation of water, which was a matter that could be dealt with; but when it was put into reverberatory furnaces, the results were very fallacious. With regard to coal, he thought nothing of heating 1 ton of scrap iron with 3½ cwt. of coal in a powdered state; but in a comparison mentioned in the Paper, 30 cwt. of coal had been employed to do the same work. Such comparisons were, of course, useless. He had paid some attention to the subject of liquid fuel years ago; he found such fuel dangerous to deal with, and he should be sorry to have anything to do with it. In a factory where there was a waste product to be had at a low cost he might be disposed to use it, especially the dead oils, the burning of which was attended with no great danger; but if such products were used to any extent the price would soon go up. He had made a calculation with Mr. E. J. Reed, C.B., M. Inst. C.E., the late Constructor of the Navy, that one large steamboat company would consume all that could be obtained. It would be found that to make the oils from shale would cost more than 18*s*. a ton.

Mr. Longridge said the extract from Bunsen and Fyfe, read by Admiral Selwyn, referred entirely to the action of steam thrown upon incandescent carbon, or coke. It was well known that when steam was thrown upon coke at a very high temperature decomposition took place: a portion of the oxygen was taken up by the carbon and formed carbonic oxide, and set free a portion of the hydrogen. That was, however, different from mixing it with the oils; and that any such result as had been stated—46 lbs. of water evaporated by 1 lb. of fuel and 1 lb. of steam—was, he thought, beyond all experience. That there was decomposition when steam was thrown upon incandescent carbon at a high temperature, there could be no doubt, and under some circumstances it would go to increase the value of the fuel to a limited extent. The main question in the Paper would have been put in a clearer light if the Author had given in each case a description of the oil that was used, and its cost per cwt. In one place the theoretical value was stated at 17·4, but instances were quoted in the Paper where it amounted to 28; so that apparently the oil could not have been the same; but

taking the latter figure as the utmost effect, it was compared with coal in the same boiler. The result stated by the Author was greatly in favour of the oil. But the coal was only evaporating 6 lbs. of water per lb. of coal—only half of what coal could be made to do in properly constructed boilers. The Welsh coal, or the north country Hartley coal, could easily evaporate 12 lbs. He had himself evaporated 12·91 lbs. without any special apparatus or any special care. The actual theoretical value was about 14·57 lbs. It was not fair to make a comparison between coal evaporating 6 lbs. in a badly constructed boiler and oil evaporating 28 lbs., which possessed nearly double the evaporative power of oil mentioned in another part of the Paper. If high-priced petroleum was used, the price was to be set against the price of coal, viz., £7 or £8 per ton against £1 5*s.* to £1 10*s.*

Mr. G. F. Deacon thought that further light ought to be thrown upon the question of the price of the oils to which reference had been made. The heavy oil from the distillation of coal tar, known in commerce as creosote oil, but being in fact a substance distinct from true creosote, had been spoken of as one of the most suitable liquid fuels produced in this country. Boiled with pitch, it was largely used in the north of England for filling the joints of pavements, and for making a bituminous concrete pavement. In Liverpool this bituminous concrete was also used for the foundations of stone pavements. For the last three or four years he had used 50,000 to 100,000 gallons a year, and had paid for it about 2½*d.* a gallon; so that the price was not a merely nominal one even at the present time.

Mr. John Phillips said, some years ago an experiment had been made at Messrs. Rennie's works to test the relative value of the dense oil and coal. The experiment lasted a month for each boiler under trial. The consumption of the oil was found to be so nearly like that of coal that no advantage was obtained by the use of it, and it was abandoned. The cost of the oil as supplied was ½*d.* per gallon. The fuel came in in lumps, and a great deal of trouble was experienced in getting it into a liquid form; besides which its smell was very offensive.

Mr. Aydon, in reply, said when he began his experiments the price of dead oil or creosote, delivered at the Victoria docks, where it was used for preserving timber, was ¼*d.* per gallon, but when the process of burning oil proved successful, one person bought up or contracted for, as a speculation, the stocks of many of the tar distillers, amounting to about 3,000,000 gallons. The market price of oil was thereupon raised first to ½*d.* per gallon,

then to ¾d., and finally to 1d. and 2½d. per gallon. When, however, the price of dead oil was from 1½d. to 2d. per gallon, it was as costly as coal fuel, so that in a country like England, where coal was cheap, it would not be worth the trouble of using it. For this reason, the Messrs. Field had discontinued its employment. But the chief value of mineral oil as a fuel was that it gave greater carrying power to ships, and enabled them to make longer voyages without the necessity of calling for fuel at any of the coaling stations. By its means he believed it would be possible to send a vessel like the "Great Eastern" (or even smaller steamers), with the present coal space or bunkers adapted to store liquid fuel, to Australia and back without opening their furnace doors (except for lighting the fires for the return voyage) or taking in fresh fuel. With regard to the quantity of mineral oil obtainable, it was found in almost every country, from Sweden to Australia and from America to Japan. It was abundant in Asia, especially in Burmah, and on the south-west coast of the Caspian Sea; also in Egypt and in Turkey, in Gallicia and in Italy. In America and Canada, new oil districts were continually being opened up; and from 1860 to 1864, about 201,000,000 gallons had been produced or pumped. In 1864 alone it was 87,000,000 gallons. In 1865 the American Inland Revenue Commission reported a daily production for four States of 12,000 barrels, of say 42 gallons each. This was equal to a daily supply of 504,000 gallons. This quantity was irrespective of the produce of the other American States and of Canada. The island of Trinidad must also be included. It was almost one entire mass of oxidised mineral oil, from which liquid fuel could be obtained in large quantities. Granting, however, as Dr. Paul had stated, that America at present only produced 600,000 tons, or 134,400,000 gallons of oil per annum, that was not the quantity which could be raised, it was the restricted production due to the influence of the American and Canadian oil ring, who allowed only a certain quantity to be placed in the market and so kept up prices. However, he had no fear but that, when the demand for liquid fuel should arise, the supply would be forthcoming, and that at a reasonable cost.

A great deal had been said and written about the absurdity of the idea of extra heat being derived from the use of steam in combination with the hydrocarbons. Dr. Paul appeared surprised at Admiral Selwyn being of opinion that such was the case. He thought it was not the first so-called phantasm or chimerical idea that had been of use to chemical science. Dr. Paul

also stated that by using liquid fuel many of the advantages of solid fuel, and the great benefits arising from gaseous fuel as in the Siemens furnace, were lost; but as all fuel must be converted into the gaseous form before it could be consumed, he did not see the drift of the argument. Chemists ignored the fact that they were not dealing with a solid body like coal, but would treat the liquid hydrocarbons as if they were solid carbon. To such view of the case he strongly objected, for here was a fuel naturally prepared the first stage towards gasification, as to effect the same object artificially six thousand or more heat units would have to be expended, which heat would become latent and so be lost as useful work. Now these six thousand heat units, added to the fifteen thousand heat units, derived from converting or burning carbon into CO_2, would give twenty-one thousand heat units, which the late Professor Rankine stated to be the amount due to gaseous carbon. American mineral oil had the following constituents: carbon, 86; hydrogen 14 = 100. Taking the above estimate for the calorific value of gaseous carbon, the result was 26,887 lbs. of water per lb. of fuel. This approximated to the calorific value calculated by Professor Hofmann. The analysis of the dead oil used in the experiments at Woolwich furnished, according to Professor Church, the following result: carbon, 86·48; hydrogen, 7·06; oxygen or refuse, 6·46 = 100. This gave, for the calorific value, 22·18 lbs. of water, after deducting the oxygen, as against 17·50 lbs. of water, taking the carbon as solid. In this view of the case there need not be much surprise at the results obtained by different experimenters with liquid fuel. Mr. Bamber had made a mistake in calculating the relative value of coal and oil fuel: for 1 ton of dead oil at ½*d.* per gallon of 10 lbs. would be 9*s.* 4*d.*, whereas the cost of 1 ton of Aberdare steam coal came to from 25*s.* to 30*s.*, or about three times as much; so that estimating the efficiency of oil at only twice that of coal, the relative cost would be as 1 to 6. He was aware that water, and therefore steam, was an oxide of hydrogen, the product of combustion, but he much doubted the assertion that it would take the same amount of heat for dissociation or decomposition into its constituent gases, if exhibited in the presence of gaseous carbon. As to using water alone as fuel, he had never heard the advocates of liquid fuel assert such a thing, although there could be no doubt but that it aided the combustion of liquid fuel when properly applied in the state of superheated steam.

Mr. Crampton's desire to keep as nearly as possible to actual practice had not been violated in the Paper, as the results stated

therein were from experiments and practice on a large scale. The answer to the question, why not use water direct as a fuel? was that no product of thorough combustion could be employed by itself as fuel and burnt again, without decomposition and separation into its constituent gases. With regard to 3½ cwt. of coal heating 1 ton of scrap, he had no doubt of the fact; but it must be recollected that Mr. Crampton put fuel into the furnace in a very different state from that of the 30 cwt. mentioned in the Paper. In fact, Mr. Crampton assimilated it to liquid fuel. He had made experiments in Mr. Crampton's domain years ago, and could assure him that with highly superheated steam and finely pulverised coal he would obtain better results than with the air blast alone. If shale oil could be sold at 18*s*. or even £1 per ton, it would be cheaper and better than coal. To Mr. Longridge's remarks on the extract from Bunsen and Fyfe, quoted by Admiral Selwyn, he would answer that what took place between steam and incandescent coke took place in the fire brick combustion chamber of the oil furnace, between the superheated steam and the liquid hydrocarbons, with this difference, that in the latter case double decomposition ensued, also that the heat required to convert the coke into CO gas was saved to be utilised on other work. The theoretical value of the oil, 17·4 lbs., as used at Woolwich, was from an analysis made by Professor Church, and the estimate was made as if the carbon was solid. The general composition of creosote or the dead oils was as follows: carbon, 78; hydrogen, 6; oxygen, 16 = 100.

The oil in all the experiments was nearly the same in composition, but tried under different circumstances; hence the difference in the results. With reference to the comparison alluded to by Mr. Longridge, where an inferior fuel had been housed, it was the coal used upon the premises, and he could not compare it with any other coal. The boiler was not a badly constructed one, it had two flues, with Galloway tubes, and was quite equal to the average work of a coal-burning boiler. With Welsh coal he had no doubt far better results would have been obtained. Mr. Phillips, in his experiments, must have been served with an oil containing a large proportion of naphthaline and sulphur, in which case the mass would have to be heated, and as he was burning a sulphide of carbon, there could be no doubt that the smell would be very offensive.

In conclusion he ventured to say that, in a few years, when the value of liquid fuel came to be more known and appreciated, no solid fuel would be burnt in houses or large towns.

Mr. S. B. Boulton remarked, through the Secretary, that he had conducted experiments in burning liquid fuel on a large scale, at various intervals during the past few years. His experiments had been almost entirely made with creosote or heavy oil of tar, this being the cheapest of all kinds of oil available for fuel in England. As regarded the kind of apparatus to be used for liquid fuel, it was desirable that it should be of the simplest possible description, and so applied to the furnace as to enable the liquid fuel to be used alternately with coal, and without much trouble or expense in the transition. He strongly objected to any apparatus in which the oil was turned into vapour in a separate generator, as he considered such a system to be more costly to inaugurate and maintain, more dangerous in its application, and extremely likely to get out of order in practical working. The system which he preferred was that of dispersing the creosote, as it entered the furnace, by a jet of steam, and letting the spray thus formed play upon a small quantity of incandescent fuel. This system worked perfectly, and on that point he agreed with Mr. Aydon. The expense of the apparatus was trifling, consisting merely of a reservoir to contain the creosote, of a small pipe, leading from thence to the interior of the furnace, and of another pipe communicating with the steam boiler, the orifice of the second pipe being immediately below the orifice of the creosote pipe. By this means oil or coal could be burnt alternately, and the change from one kind of fuel to the other could be made at half an hour's notice as often as required.

The next question was one of cost. Creosote, although the cheapest kind of liquid fuel in this country, was not a refuse product. It might fairly be calculated that all the creosote manufactured in Europe from the distillation of coal tar was required for the preparation of timber. The price of creosote had varied during the last few years from *2d.* to *3d.* per gallon, sometimes reaching $3\frac{1}{2}d.$ Now he had found, upon an average of a great many trials of different boilers, that 1 ton of creosote would do the work of from 2 to $2\frac{1}{2}$ tons of coal. Assuming, for the sake of calculation, that creosote was worth *2d.* per gallon, taking 220 gallons to the ton, and supposing, moreover, that 1 ton of creosote performed twice the work of 1 ton of coal, it would be seen that the cost of the creosote burnt in place of 1 ton of coal would be *18s. 4d.* This calculation, however, did not state the whole of the case. The production of creosote being limited, it would rise greatly in price if a large demand sprang up for it for consumption as fuel. It might be roughly stated that, for consumption in England, it would be a cheap fuel at *1d.* per

gallon; problematical as to economy at 2*d.*; and too expensive at 3*d.* The aspect of this question, however, changed if considered with respect to the consumption of liquid fuel by large steam vessels, and upon long sea voyages. The cost of fuel consumed on board of a steamer consisted not only of the price paid for it at the port of departure, but it was increased by the necessary sacrifice of tonnage-capacity in the vessel on board which it was consumed; and this last item of cost increased with the length of the voyage. If, therefore, creosote as a fuel would do the same duty as twice its weight of coal, it might, under certain circumstances, and upon long sea voyages, prove the more economical fuel. It might at times be of great importance that a vessel of war should be able to cruise for a long period before being obliged to put into port for a fresh supply of fuel. It would appear that, by burning liquid fuel, she could keep at sea for at least double the time that would be possible if she were burning coal. This led to the suggestion that it might perhaps be desirable for the British Admiralty to try further experiments on a large scale with some such simple form of apparatus as that which he had described, especially as creosote could be obtained in greater abundance in England than in any other country.

Mr. O. C. D. Ross observed, through the Secretary, that the Paper dealt with the various modes hitherto adopted for burning liquid fuel, and with its application, first to boilers, secondly to metallurgical operations. It described plans by which oil was driven into a furnace as spray, together with steam, or compressed or heated air; but the excessive quantity of smoke and soot showed that it was being incompletely consumed, and these methods had been properly abandoned. Excepting for the purpose of heating, or converting the oil into vapour, air must always be the preferable medium for conveying it into a furnace, because it supplied the oxygen required for its combustion. It should be borne in mind that 1 lb. of carbon required for its combustion $2\frac{2}{3}$ lbs. of oxygen, or 11·61 lbs. (about 150 cubic feet) of air, and that consequently, whatever process of combustion might be adopted, this minimum quantity of air must be mixed with the oil vapour when driving it into a furnace. Even coal gas was not completely consumed unless mixed with sufficient air, as in a Bunsen burner. If steam was added, the volume of the products of combustion would be increased, over which the heat would be distributed, and the thermal effect of the fuel would be diminished; but as all heavy oils must be heated in order to be converted into vapour, which was an indispensable condition for

ensuring their complete combustion, it was possible that local conditions might sometimes counteract the disadvantage of using steam. It appeared to him that a consideration of the cost of liquid fuel, as compared with coal, made it impossible to contemplate its application to all purposes for which coal was used. The experiments with creosote at Woolwich, in 1866-67, caused the price to be raised from ¾*d.* per gallon (or say 15*s.* per ton) to 4*d.* and even 6*d.* per gallon, and it was at that time asserted that the total annual production of creosote in England amounted to about 100,000 tons. So also the total quantity of petroleum now raised in America per year was under 1,000,000 tons, whereas the annual consumption of coal in Great Britain alone was now about 140,000,000 tons. At 8*d.* per gallon, the present cost of petroleum (or coal oil) was about £9 per ton. He could not, therefore, agree that oil was the "coming fuel"; the advocates of its application for all purposes would defeat their own object if they succeeded. There could, however, be no doubt that for certain special purposes, and in certain localities, liquid fuel would be both more economical and in other ways more advantageous than coal. For example, it would be far too costly for use, under ordinary conditions, in stationary boilers in England, because it would then have to compete with coal on a simple comparison of the calorific effects and relative cost, the first of which might be as 1 to 2½ or 1 to 3, the second as 1 to 9. But on the other hand, it might be advantageously applied to the marine boilers of large ocean steamers, of pleasure yachts, and of men-of-war, because of the great saving which would be effected in the bulk of the fuel, besides its superior cleanliness, reduction in the number of stokers, absence of smoke, &c. Again, when high temperatures were required in a confined space, as in some metallurgical operations, vaporised oil had the advantage that it would burn with a much greater thermal heat, because it did not require the excessive quantity of air which was necessary for the disintegration of coal, and the waste of heat through the chimney of an ordinary reverberatory furnace would be enormously decreased when using oil vapour driven into the furnace in combination with air. Where coal was expensive and oil was cheap, as in the Caspian Sea and on the coast of South America, liquid fuel would be the cheaper of the two. Professor Macquorn Rankine had pointed out that whereas the evaporative power of solid carbon was 15, that of gaseous carbon (such as was obtained with oil vapour) was 21, whilst its useful thermal effect in metallurgical operations was many times greater than that of coal. Different qualities of oil required different temperatures

to convert them into vapour; one oil might require to be heated to 400°, another would vaporise at ordinary temperatures. The latter would be gradually reduced in temperature by the vaporisation, and, unless that loss of heat was compensated, would give off a gradually diminishing quantity of vapour. These circumstances must be attended to when employing liquid fuel, and made it necessary that it should be used with care and under intelligent direction.

Mr. AYDON desired to reply, through the Secretary, to some of the remarks made by Mr. Ross, who assumed that the price of dead oil or liquid fuel was from 6*d.* to 8*d.* per gallon. This was out of the question, although no doubt the Government were charged that price. Whatever might be said, he should retain the opinion that within a comparatively short time no solid fuel would be burnt. Something like a corroboration of the theory held by Admiral Selwyn and himself, in contradistinction to chemists generally, was the dissociation of steam into its constituents more readily and at a lower temperature than was commonly supposed. From a brief account of experiments made before the American Scientific Society on this subject, he gathered that, when steam was passed through a platinum tube or coil at a temperature equal to a dull low red heat of wrought-iron plate, the resultant gases of decomposition were collected in a receiver over mercury. After sufficient had been collected, a lighted taper was inserted, when an explosion took place, thus showing that the gases were in the same proportion as before dissociation, and proving that the dissociation was not owing to the loss of oxygen to the metal of the platinum pipe.

Sect. II.—OTHER SELECTED PAPERS.

No. 74.—"Machine-Tools."[1] By Percy Ruskin Allen, Stud. Inst. C.E.

In this Paper it has not been the object to give an historical account of the introduction of machine-tools, but rather to treat of their construction and application as they at present exist. Since the Great Exhibition of 1851 no very striking change has taken place in the design, nor in the principles which govern the construction of ordinary machine-tools. A few years before that date Mr. Whitworth, now Sir Joseph Whitworth, M. Inst. C.E., had introduced the practice of scraping to true planes the sliding surfaces of his tools; and it was principally this, and his substitution of rigid hollow castings in the place of ribbed frames, that brought machine-tools to their present accuracy and precision of operation; but although no radical alterations may have been made within the last twenty-five years in standard machine-tools, yet there have been many improvements in points of detail; and in some classes of tools, particularly those used for producing work with duplicate and interchangeable parts, a notable development has taken place. The classification which has been followed is that adopted by Mr. Robert Mallet, M. Inst. C.E., in his review of the Exhibition of 1862. The tools are divided according to the way in which they produce their effect upon the work, and are arranged under six heads, viz.: Tools of Section, Tools of Abrasion, Tools of Detrusion and Penetration, Tools of Inflection, Tools of Contusion, and Tools of Compression.

Tools of Section.

By tools of section are meant those tools which act with a cutting edge proper, such as lathes, planing, shaping, slotting, drilling, boring and screw-cutting machines. The turning lathe is the oldest of these, having existed in a rude form at a very early age. The clock and watch makers of the seventeenth and eighteenth centuries did much to develop tools of precision, and

[1] This communication was read and discussed at a meeting of the Students on the 19th of January, 1877, and was awarded the Miller Scholarship in the Session 1876–77.

constructed lathes for their special purposes, which operated with a considerable degree of accuracy. It was not, however, until after the slide rest had been applied to iron-working lathes by Maudslay, about the beginning of the present century, and self-acting feed motions had come into use, that engineers' lathes assumed their present form. Various improvements and additions have from time to time been made, and at the present day a well-appointed self-acting lathe is a tool of universal application. Sliding, surfacing, boring, and the cutting of internal and external screw threads are operations that may be performed in lathes to be met with in any engineer's workshops, and by the addition of a few attachments, milling, wheel-cutting, chasing, grinding, &c., can also be accomplished. In sliding, which is the production of cylindrical forms by causing the work to revolve, and by moving the cutting tool parallel to the axis of revolution, the work is suspended between two conical centres, one of which revolves with the cone spindle while the other is stationary. The fast headstock in which the spindle revolves is fixed down to one end of the bed, and the loose headstock, holding the dead centre, can be slid along and clamped in any position to suit the length of the work, and the carriage on which the slide rest is fixed traverses on the top of the bed between the headstocks. The first requisite of a lathe intended to produce accurate work is that the spindle should run exactly true, with a view to accurate adjustment, and to take up any slackness from wear. The spindles of lathes up to 12 or 15-inch centres usually have conical journals which revolve in hardened steel bushes in the headstock. In larger lathes the journals are parallel, and the bearings are of gun-metal or bronze, and in halves, as conical bearings cannot be used where there is much overhanging weight on the spindle. For the smaller and medium sizes of sliding and screw-cutting lathes a cone pulley with four or five steps and back gearing, giving eight or ten different speeds to the spindle, is generally found to afford a sufficient variation of speed for ordinary work; but surfacing lathes and the larger break lathes usually have treble gearing, so arranged that the slow speed is communicated to the face-plate by a pinion working in a rack cast on the back.

Figs. 1 and 2, Plate 5, show a sliding and screw-cutting lathe with 12-inch centres. It will be seen that there is a gap or recess just in front of the fast headstock; this is to admit work of a larger diameter than could be turned over the bed. When not in use, a bridge piece is placed over it, and the carriage can traverse up to the headstock. In break lathes the bed is movable on a base plate,

and can be withdrawn from the fast headstock; and in surfacing lathes the bed and loose headstock are frequently dispensed with, and the slide rest mounted on the top of a column on the base plate. The form of lathe-bed used in this country is shown in Fig. 3, and that used in America in Fig. 4. In the English bed there are two flat surfaces, with their inner edges square and their outer edges inclined at angles of 50°. The two headstocks fit down on the bed, and are kept in line by the inner sides, while the carriage extends right across, and is guided by the inclined outer edges, a loose strip being provided on one side to take up any wear. The American bed has four inverted V's on the upper side; the headstocks clamp down on the two inner ones, and the carriage slides on the outer ones, or sometimes on all four, and is prevented from rising by gibs, or by a weight in the centre.

The necessary feed motions for the tool are always derived from the revolution of the cone spindle. In screw-cutting the carriage is traversed by a leading screw driven from the spindle through a series of change wheels, which may be arranged to cut screws of different pitches; sometimes the leading screw is also used to traverse the carriage when sliding, but in many lathes a separate shaft is employed to convey motion to the carriage for sliding and surfacing, and the leading screw is kept exclusively for screw-cutting. The lathe shown in Figs. 1 and 2 has a convenient arrangement for reversing the direction of the feed, by means of a pair of pinions which work with each other, and can be brought alternately into gear with a pinion on the end of the spindle; the bracket which carries this reversing motion serves also to support the tail pin that takes the end thrust of the spindle. In the duplex slide rest arrangement of Sir Joseph Whitworth two slide rests are mounted on the carriage, and the tools act on the opposite sides of the work. In capstan-rest or turret lathes a series of tools are fixed in a circular block, and can be brought to operate on the work in succession. It would not be possible here to give an account of the various purposes lathes are applied to; it has been already said that the lathe is a machine of most extended application. In the ornamental lathes used for amateur turning, objects of almost every conceivable form may be produced by the aid of geometric chucks and cutting frames; and automatic arrangements of a similar nature have been successfully used in Messrs. Stephenson's locomotive works at Newcastle-upon-Tyne, for turning glands and irregular work of that kind.

Planing Machines.

Next to the lathe the planing machine is the most important tool in a machine shop. The primary object of the lathe is to produce cylindrical forms, that of the planing machine is to produce plane surfaces; and these are the two ruling forms in machine construction.

In the planing machines first used in this country the table carrying the work was traversed by a chain, but in modern machines either a screw, or rack and pinion, is used; in both cases the general arrangement of the machine is the same. The tool box is attached to a small slide on a saddle, which is movable on a cross slide supported by two uprights bolted to the bed. In machines worked by a screw, a nut is fixed on the under side of the table, and the screw extends the whole length of the bed, the driving gear being at one end; but in rack-driven machines a pinion immediately under the cross slide gears into a rack beneath the table. Some engineers prefer screw planing machines, as giving a smoother motion to the table, but by far the greatest number of machines in use at present are worked by a rack. The irregularities that occur with a rack motion arise from the torsional spring of the shafts which give motion to the pinion, and from the imperfect gearing of the pinion with the rack; the latter defect may be mitigated by using a step rack, or by cutting the teeth in a machine.

The American planing machines almost always have cut teeth, and instead of a pinion of small diameter, a large idle wheel is used to gear with the rack; this permits the teeth to be made of a more advantageous shape. In a form of planing machine made by Messrs. Sellers, of Philadelphia, U.S.A., a peculiar combination of screw and rack gearing is employed. To traverse the table, a spiral pinion, in reality a portion of a coarse-threaded screw, is fixed on the end of a short shaft that extends diagonally across the bed, and is driven through bevel gearing from belt pulleys at the side of the machine. The spiral pinion gears with the teeth of a rack on the under side of the table, and imparts a steady and even motion to the work. The teeth of the rack in this case are made straight on the face, but are inclined at an angle of 5° with the centre line of the table. Planing machines are generally intended to cut only in one direction, and are made to run back about three times as fast as when cutting. Where they are arranged to cut both ways, either the tool box is caused to turn half a revolution at the end of the traverse, as in the Whitworth machines, or independent tools are used mounted on

separate slides, so that they cut alternately. In this case the table runs at the same speed in both directions. Reversing is effected by stops which can be clamped in any position along a groove in the side of the table. The stops strike a lever which shifts the belt, and, in English machines, also works the feed motion; in American machines a separate motion is used for feed. Figs. 5 and 6 show a rack planing machine made in Manchester, which is a good example of recent practice. Motion is conveyed to the feed wheels at the end of the cross slide by mitre gearing on a small vertical shaft, and this is a much neater arrangement than the reciprocating rods sometimes used. The tool box is hung on a pivot so that while the table is running back the tool drags loosely over the work; but some makers apply an automatic motion to lift the tool clear. A self-acting downward or angular feed motion is conveyed to the tool slide through the shaft that is placed above the screw in the cross slide. The tables of planing machines slide in V's in the beds, and care should be taken to provide some means of keeping these sliding surfaces well lubricated. The V's of ordinary-sized machines are made at angles of about 100°, but in large machines, where the tables are heavy, the angle is more obtuse. In the smallest machines, where the traversing motion is derived from a crank, the table slides on flat surfaces, and is kept in place by inclined strips, in a somewhat similar manner to the saddle of a lathe.

Shaping Machines.

In these machines the cutting tools are of similar shape, and remove the metal in the same way, as in planing machines; but they are intended to operate on a smaller class of work; the work is stationary, and the tool is attached to the end of a reciprocating ram. A crank motion is usually employed to work the ram, and as the tool only cuts in one direction some quick return arrangement is necessary. In the well-known quick return motion used on the Whitworth machines, the arm carrying the crank pin turns on a stud eccentric to the wheel carrying the driving lug, which therefore acts at a varying distance from the centre of the crank arm. In another arrangement, frequently adopted, the crank pin works in a slotted link, which is pivoted at one end to the frame and connected to the ram at the other, or in some cases oval or elliptical wheels give the requisite motion. One firm of toolmakers obtain a quick return motion in their machines by segmental gearing, so disposed that segments of different radii come into action alternately. In all these arrangements the length of

stroke is changed by altering the throw of the crank pin, and the position in which the cut takes place depends upon where the connecting rod or its equivalent is clamped to the ram. In small machines, up to 6 inches stroke, the feed motion is obtained by applying a self-acting traversing motion to the table carrying the work; but in larger machines the work remains stationary, and the headstock carrying the ram is traversed along the bed, prior to the commencement of each cut. Two tables are generally provided, and in some machines three tables and two headstocks are mounted on one long bed. A screw is used to traverse the headstock along the bed; in the most improved machines the screw is stationary and the feed gearing actuates a nut that revolves in the headstock, so that the feed can be controlled by the attendant without having to go to the end of the bed, as in the old arrangements. A shaping machine of modern design is shown in Fig. 7. The tool box is pivoted as in a planing machine, and is attached to a small slide which can be swivelled on the end of the ram for taking angular cuts, and for shaping internal curves. This swivelling motion is controlled by a worm which gears into a segment formed on the slide, and in the best machines the worm is made in two pieces, so that it can be set up to compensate for wear. A self-acting feed motion derived from the movement of the ram may be applied either to the end of the worm spindle or to the feed screw of the slide by a ratchet wheel, with a square hole in the boss. For shaping external curves and circular work, such as the eyes of levers, &c., a mandrel projects out from the front of the bed. It is provided with two cones to clutch the work centrally, and has an automatic feed motion by a worm-and-worm actuating by ratchet gearing at the end of the bed. The pawls for working the ratchet wheels in the feed motions of planing, shaping, and slotting machines are reversible, so that by merely turning them over they transmit the feed motion in opposite directions. A pawl of this kind is shown in Fig. 8. A spiral spring on the pawl tends to keep a small plunger in contact with one of three flat places on the stud upon which the pawl works, and thus retains it in gear on either side, or in a position midway between the two, and out of gear.

Slotting Machines.

These differ from shaping machines in that the tool has a a vertical instead of a horizontal cutting movement; but, as in shaping machines, the tool moves to make the cut, and cutting

only takes place in one direction. The length of stroke is comparatively short, seldom exceeding 2 feet in the machines most frequently used in engineers' shops. A great deal of work may be done equally well and conveniently in either a shaping or a slotting machine; but there are certain operations, such as paring out the insides of inclosed holes or cutting key-ways in the bosses of wheels, that cannot well be performed except in a slotting machine. In the standard pattern of machine, the tool is attached to the bottom of a ram that has a vertical movement in a slide formed on the upper part of a frame overhanging the table upon which the work is fixed. A crank disk with a pin of adjustable throw gives motion to the ram, through a connecting rod which is clamped to it by a bolt passing through a slot at the top, so that the cut may be made to take place at a greater or less distance from the surface of the table. In some machines a screw passing through the shank of the bolt is provided, for altering the adjustment of the ram; this is a useful addition, as it prevents the ram accidentally dropping when the bolt is unclamped. Although the tool only cuts in one direction, it is only recently that quick return motions have been used in slotting machines, and even now they are not universally applied. In some machines a counterweight slightly heavier than the ram and tool is connected directly to the ram, and this prevents any drop, or back lash, arising from the wear of the connecting rod fastenings. The table on which the work is placed has T grooves across it to receive clamping bolts, and is usually made circular and mounted on compound slides. Thus three distinct feed motions may be given to the work, viz., the longitudinal and the transverse motions of the compound slides, and a circular motion obtained by revolving the table on the upper slide. These motions are independent of each other, and may be worked automatically or by hand; the automatic motion being derived from a cam on the crank shaft. Sometimes a tilting adjustment for the table is also provided, so that it may be slightly inclined when cutting keyways in the bosses of wheels.

The disposition of the feed gearing in a manner most convenient for the attendant is a point of considerable importance; perhaps no other machine-tool requires so much regulation and adjustment as a slotting machine.

The large machines used in locomotive works for slotting out the frame plates usually have three heads that can be operated simultaneously. These are supported on transverse cross

heads that extend across the bed of the machine. The slotting heads have a transverse motion on the cross heads, and the cross heads a longitudinal one on the bed. By combining these two movements, the tool may be made to slot round a curve of any outline. In these machines the tool is held in a circular tool box that can be rotated by a worm, for finishing small curves and setting the tool. Slotting machines are sometimes combined with drilling and with planing machines. A large combined slotting and planing machine has been lately made by Messrs. Fairbairn, Kennedy, and Naylor, for the Barrow Shipbuilding and Engineering Company. It will plane a length of 20 feet and slot a depth of 10 feet. Two slotting heads are mounted on opposite sides of a vertical column, which stands at the side of the bed; when the machine is used for planing, the table is worked to and fro on the bed by a rack and pinion motion, and the slotting heads are moved gradually on the column; but when the machine is used for slotting, the heads are worked up and down the column by screw gearing, and the feed motion is applied to the table.

Drilling and Boring Machines.

The distinction usually understood between the operations termed drilling and boring is, that drilling is taken to mean the production of holes in a solid substance by tools which remove the material for the entire diameter of the hole; while boring is the operation of enlarging a hole that already exists. In fact boring may be considered as a process of internal turning, and in many cases may be well performed in the lathe; but for general purposes separate machines are usually employed. In the drilling machines most commonly used the spindle carrying the drill runs in bearings in the upper part of a vertical frame that projects over the table supporting the work. A good example of a drilling machine of this kind is shown in Fig. 9. The cone pulley is on a horizontal shaft, which gives motion by mitre wheels to a vertical tube encircling the drill spindle, and causes it to revolve by a feather entering a keyway that extends the whole length. The downward feed motion is communicated to the spindle either through a rack or a screw connected to it by a running joint, that permits the spindle to revolve, but controls any vertical movement. The self-acting motion for the feed is derived from the horizontal shaft through a small belt running on cone pulleys to obtain the necessary variations of speed; but this gearing is arranged so that it can be disengaged, and the spindle run

quickly up or down by hand. The table on which the work is placed is mounted on a bracket, which swings on a saddle capable of being raised and lowered on the front of the frame. In the vertical drilling machines made in the United States the whole of the upper part of the frame is supported by a turned cylindrical column, upon which the table can be moved up or down, or swung round out of the way. Instead of having mitre gearing to connect the cone pulley shaft with the spindle tube, as in British machines, it is customary to use bevel wheels that reduce the speed of the drill spindle from one-third to one-half that of the cone pulley. But at the late Philadelphia Exhibition some drilling machines were shown by Messrs. Sellers in which the drill spindle was driven by a belt direct from the cone shaft without the interposition of gearing; and by this arrangement a smooth motion was imparted to the drill. A neat device is used on the drilling machines made by the Pratt and Whitney Company, of Hartford, for showing the depth the drill has penetrated without withdrawing it from the hole. It consists of a disk with a graduated edge that can be clamped to the pinion that feeds the spindle down, and is read off by an index pin fixed in the frame. In radial drilling machines in which the drill spindle can be moved in or out, a radial arm or jib is used for operating upon work which cannot be manipulated under an ordinary vertical machine. In some cases the jib is arranged to swing round a vertical column at one end of the bed plate; but in another arrangement the inner end of the jib turns in bearings on a saddle that can be raised. On a hollow standard, motion is communicated to the drill spindle through a shaft extending along the jib, which derives its motion from the cone pulley through a vertical shaft in the standard. In modern machines the hand wheel for traversing the spindle carriage along the jib is placed on the carriage itself, instead of at the end of the jib, as was formerly the practice. In Asquith's radial drilling machines the motion for slewing the jib round is also arranged to be worked from the carriage; so that all the motions are under the immediate control of the attendant, and time is economised in adjusting the drill. In multiple drilling machines, used by bridge-builders and boiler-makers for drilling plates, angle irons, &c., a number of drills operate simultaneously upon the work. In the usual arrangement of machines the spindles are placed in a line on a horizontal cross head, and are driven by tangent gearing on a long shaft.

Of late years various attempts have been made to devise some efficient means of driving portable drilling machines, as it often

happens that it is impracticable to bring the work beneath any fixed machine, and the tedious process of hand drilling has to be resorted to. Steam and compressed air, conveyed through flexible pipes, have been tried in some places, but they require a small engine on the drill frame, and this makes the arrangement rather unwieldy. In Thorne's portable drilling machines motion is conveyed to the drill through a light endless rope, that passes under a weighted idle pulley, and is kept at an even tension whatever distance the machine may be placed from the counter-shaft. Within the last few years cylindrical twist drills have to a great extent superseded the old form of flat drill, and there are several advantages attending their use. They withdraw the shavings while cutting, and leave a smooth surface in the interior of the hole, and, when dull, merely require to be ground, and do not need to be re-drawn or tempered, as they are of the same diameter and temper throughout. These drills are made principally by the Morse Twist Drill Company, of New Bedford, Mass., from steel wire, No. 20 wire gauge, up to a size that weighed with the holder 80 lbs. An example of a twist drill is shown in Fig. 10.

Traversing or slot drilling machines are now generally used for cutting slots, grooves, keyways, cotter holes, &c. The principle upon which these machines operate is the combination of a lateral movement with the rotary motion of the drill. There are several forms of machine in use in this country, but in most of them the drill spindle revolves in a headstock sliding on a bed, like that of a shaping machine, and is reciprocated by a crank disk driven through elliptical wheels, in order to obtain an equal traversing speed. The downward feed motion for the drill spindle is worked by a cam that comes into action at the end of the traverse. In Shanks' duplex slot drilling machines two horizontal drills operate simultaneously upon opposite sides of the work, and as they only require to be the length of half the depth of the slot, they are proportionately stiffer. The drills used for slot drilling have the neutral part at the centre removed, and are fork-shaped, with the opposite cutting edges in the same plane.

Boring Machines.

Boring is an operation which, within certain limits, may be efficiently performed in the lathe by fixing the work in a chuck, and holding the tool in the slide rest; or by using a boring bar and supporting the work upon a table placed on the carriage.

Vertical drilling machines may be also used for boring purposes

if provision is made for steadying the end of the boring bar; and most machines have a hole in the table to receive a steel bush for this purpose. But in the machine usually employed for general boring the bar is horizontal, and the headstocks and brackets which support it are fixed to a large planed bed plate, and have graduated adjustments both vertically and horizontally, so that, when a piece of work is once set, any necessary number of holes may be bored without moving it. Some difference of opinion exists as to whether it is better to use horizontal or vertical machines for boring large work, such as the cylinders of marine and pumping or blowing engines. Vertical machines seem to be generally preferred, but in deciding upon the form of machine to be adopted the position the cylinder will afterwards occupy ought to be taken into consideration.

A peculiar form of machine, called a vertical boring mill, is extensively used in the United States. An example of a mill of this kind, made at the Niles Tool Works, is shown in Fig 11. Vertical boring mills may be considered as surfacing lathes with horizontal face plates; they are used for doing a great deal of work that in this country would be done in the lathe, as its horizontal position renders it very convenient for setting and fixing heavy work upon the face plate. This is supported on a centre spindle, 12 inches in diameter, which works an adjustable steel foot step, that can be lowered to allow the face plate to rest on an annular bearing under its extreme outside edge, when a heavy piece of work is being operated upon. It will be seen that two tool-holders are placed on the cross slide, and are balanced by a counterweight attached to the end of a chain. The Clements driver shown on the face plate and the dead centre on the cross slide are used when the machine is employed for pulley turning, an operation for which these machines are well adapted. At the Cincinnati Exposition in 1872 a pulley 30 inches in diameter and 10 inches wide on the face, and of ordinary hard metal, was turned (two cuts being run over it), and had the edges trimmed in forty-two minutes by one of these machines. In some of the boring mills made by Messrs. Bement, of Philadelphia, a slotting attachment is fixed to the cross slide, so that after a pulley has been bored and turned, the keyway may be cut before it is removed from the machine.

Screwing and Tapping Machines.

It has already been said that the cutting of internal and external screws is an operation that can be well performed in the

lathe. Screws for traversing purposes, which require to be very accurate, are generally produced in that way; but for threading bolts and nuts, and work of a similar kind, machines using dies and taps are commonly employed. Screwing machines may be divided into two classes: in one the dies are stationary and the work revolves, in the other the work is stationary and the dies revolve. Revolving die machines are now generally used, and have the advantage of permitting the work, when finished, to be withdrawn without stopping the machine; this is accomplished by causing the dies to move radially outwards in the die box. In Sellers's screwing machine the dies are worked by a cam plate at the back of the die box, which by means of two wheels of different diameters can be made to overrun the die box when it is desired to withdraw the work. Brown's screwing machine can also be operated while in motion, the dies being moved radially by means of a bell-mouthed ring which acts on the rounded ends of the dies. Considerable attention has lately been given to perfecting screwing machinery, and some of the machines now made are capable of turning out very good work, in some cases almost equal to that produced in a lathe. The long screws used in the Boomer and Boschert presses are 3 inches in diameter, and have right and left hand threads of a peculiar saw-shaped section formed upon them; these screws were formerly cut in the lathe, but are now screwed in one of Bowker's screwing machines, in two cuts up, and in a much shorter time.

The studs and screws used for fastening together small pieces of machinery are generally made in turret-head lathes, arranged specially for the purpose. The rod or wire that they are cut from is fed through the spindle, which is hollow, and has a self-centering chuck at the front end; the necessary tools to turn the shank and cut the thread are fixed in a turret, and the stud, when completed, is cut off by a tool mounted on a separate slide close to the headstock.

Tapping, which is the converse of screwing, is usually done by substituting a tap for the dies in a screwing machine; but where the hole is small, or does not pass through the work, there are objections to this plan. There is an ingenious form of tapping machine used by gun-makers and sewing machine manufacturers for that kind of work. One of these machines is shown in Fig. 12. The tap is clamped in a chuck on the end of a spindle, which runs in bearings in a small headstock, and has a certain amount of end movement allowed it; two pulleys run loose in opposite directions on the spindle, and the one at the front of the

headstock revolves faster than the other. The work to be tapped is placed in a small rest, or holder, at the end of a bar that slides through a loose headstock. When the hole is to be bored, the work is pressed slightly against the end of the tap; this moves the spindle endways, and causes a lug to come in contact with the back pulley, which makes the tap revolve in the proper direction for cutting. The action of the tap draws the work forward until an adjustable collar on the bar prevents the holder moving any further; the continued action of the tap then draws itself forward in the work, and moves the lug out of gear with the back pulley, and the tap ceases to revolve. To withdraw the tap, the work is pressed gently in the opposite direction, when the lug on the spindle comes in contact with the front pulley and the tap is run quickly out.

Special Machine-Tools.

In this section the Author has considered briefly some of the peculiarities and adaptations of machine-tools contrived for special purposes. Many organisers and proprietors of engineering establishments have of late shown a marked disposition to confine themselves to the manufacture of some speciality, and devote their whole attention to diminishing the cost of production by the most advantageous division of labour, and by the use of automatic tools. The large small-arm and sewing-machine factories are perhaps the best instances that can be given of works where the intelligent division of the various workshop processes has been most successfully carried out. One noticeable result of the employment of special machine-tools in cases like this has been the increasing adoption of the interchangeable system. It is needless to dwell on the conveniences and advantages that result from the use of duplicate pieces in the working parts of machinery; many instances will at once present themselves. The duplication of pieces may be carried on in an ordinary workshop without the aid of special tools by a careful system of gauging; but it is usual to employ a class of machine-tools specially adapted to the purpose, which may be termed tools of reduplication. Milling or shaping with revolving cutters is the basis of most of the operations in establishments where the interchangeable system is practised. The term "milling" was originally applied to the process of reproducing patterns by transferring the irregularities of a hardened steel roller to the work, by causing them to revolve in contact. The heads of screws in philosophical instruments are produced in this way, which is in

reality a process of metal embossing. Now the word "milling" has come to be used as denoting all those machines that operate with serrated rotary cutters, and it is in this sense that the word is used here. A milling machine may be considered as bearing the same relation to metal-working machinery that a moulding machine does to wood-working. The milling cutters are of steel, and turned to exactly the reverse of the outline it is desired to produce on the work before being serrated and hardened. When the centre is more than 2 inches wide the teeth are generally cut slightly spiral, so as to obtain a shaving cut. Where it is necessary to have a long cutter, it is made in several lengths, which are clamped together on a mandrel, and revolve as one piece. In the ordinary arrangement of milling machines, one end of the mandrel, carrying the cutter, is held in a spindle driven by gearing like a lathe spindle; while the other end is supported by a dead centre, carried on an arm extending from the headstock, or, in some cases, held in a separate loose headstock. A number of the pieces to be milled are fixed down to a table that moves in a line at right angles to the spindle, and is fed forward automatically until an adjustable stop throws the feed motion out of gear; the table is then run quickly back by hand, the milled pieces removed, and the operation repeated on a fresh set. Edge-milling or profiling machines, as they are called in America, are used for work that is irregular in more than one dimension, or that has to be milled to curves of varying radii. In these machines the cutter is fixed to a vertical spindle, which is mounted on a movable slide that has a guide pin attached to it, and is controlled by a template on the same table as the work, so that a form is reproduced upon the work that combines the outline of the milling cutter with the guiding surface of the template.

Apart from their special applications for reduplicating work, milling machines are in some places used as substitutes for shaping and slotting machines. This is particularly the case in America, where milling is practised as a workshop process to a much greater extent than it is in Great Britain, and where universal milling machines are extensively employed. A very complete machine of this kind, made by the Brown and Sharpe Manufacturing Company, is shown in Figs. 13 and 14. It will be seen that the feed motion is communicated to the carriage through a small telescopic shaft fitted with Hook's joints, so that the slide in which the carriage moves may be set at an angle with the centre line of the spindle. The small headstock carrying the centre at the end of the carriage has also an angular motion in the vertical plane, so arranged that, whatever the angle may be, the centre remains in gear with the feed

motion. These additional movements render the machine capable of a wide range of application, for besides ordinary milling a great variety of other work, such as reamers, twist drills, milling cutters, rosebits, &c., may be produced, and the teeth of spur and bevel wheels may also be cut. The cutters used in these machines are of peculiar shape, and are of the same cross section throughout, so that by grinding them on the face they may be sharpened without altering their form. Machines having rotary cutters with detached teeth are sometimes used for operating upon a larger class of work, where it is necessary to take heavy cuts. The Author has seen some large machines of this class in marine-engine works at Glasgow, where they were used for facing frames and condensers. Machines of this kind are also employed at Crewe for cutting out locomotive cranks, and the ends of the girders for the Gilbert Elevated railway in New York were squared up in a machine using rotary cutters constructed especially for the purpose. In machines for cutting the teeth of wheels a rotary cutter of the shape of the space between the teeth is caused to move across the face of the blank wheel, which is turned round a certain distance previous to the commencement of each traverse, in order to form a fresh tooth. In some machines, such as those of Thomson and of Sellers, this dividing movement takes place automatically, and when once started the machine goes on till the wheel is finished; but in ordinary machines the division is done by the workman. Change wheels are usually interposed between the dividing handle and the mandrel, to enable teeth of different pitches to be cut. In the latest form of dividing apparatus, used by Mr. Scott, of Manchester, on his wheel-moulding and cutting machines, these are dispensed with; the dividing handle turns the mandrel direct through a worm-and-worm wheel, and the pitch is regulated by the number of times, or portion of times, the dividing handle is turned round a graduated disk, which is provided with a peculiar arrangement of adjustable stop that limits the movement of the handle.

The teeth of bevel wheels may be cut to an approximate form by inclining the blank at an angle, and subjecting it to the action of two or more circular cutters; but it is only possible to get a theoretically accurate result in machines using reciprocating tools. Machines of this kind have been constructed in this country by Hunt, and by Dodge, of Manchester, and a large machine made by Mr. Corliss, the inventor of the Corliss engine, was shown at the Philadelphia Exhibition, where the slide on which the tool worked was controlled by a template tooth of large size.

TOOLS OF ABRASION.

Coming now to tools of abrasion, the most noticeable thing about this class of machinery is the revival of emery grinding as a workshop process. Not the old haphazard plan of grinding with loose emery, but with emery cemented into solid wheels, or disks, which are run at a high speed; and which reduce the metal they operate upon with but slight damage to themselves. One of the objections to the use of the old wheels of natural stone was the difficulty of keeping them true, owing to the inequality of the grit and the existence of hard and soft places in the stone; but with artificial wheels and stones perfect uniformity of texture can be secured, and the cutting particles may be of any desired fineness, from angular pieces nearly the size of peas down to dust. Manufacturers of emery wheels generally keep secret the nature of the composition they use to cement the emery together, but resin, brimstone, shellac, and pitch are the principal ingredients in some of the mixtures; vulcanite and celuoid, a preparation of gun-cotton, are also to some extent used. In Ransome's emery wheels the emery is bound together by an insoluble silicate which forms, when set, an artificial stone, but being rather softer than the emery, it does not project when the latter is worn out. There is a considerable difference between the speeds which the different makers recommend their wheels to be run at. In Bollman's emery grinding machine the wheel has a surface-speed of 6,000 feet per minute. The Tanite wheels are meant to run at about 5,500 feet, and Ransome's silicate wheels do best at a speed of between 4,000 and 4,500 feet; while the Union Stone Company, of Boston, U.S., recommended that their wheels should only have a surface-speed of 3,500 feet per minute, and for tool grinding even less. Most makers test their wheels before sending them out, and if they are originally sound, and are not forced too tightly upon the mandrel, they rarely burst while run within the specified speed. In the simpler kinds of emery grinding machines used by engineers for fettling or cleaning castings and rough miscellaneous work, the article to be ground is merely laid on a rest and pressed by hand against the face or side of the wheel. But within the last two or three years the applications of emery wheels have been considerably extended, and in some of the machines now made the arrangements for holding and guiding the work are as elaborate and accurate as is a planing or shaping machine. Machines using emery wheels have the advantage of being able to operate

upon hardened or on chilled surfaces. In Newman's emery planer the revolving wheel is mounted on a slide that has a reciprocating movement at right angles to the feed motion of the table. It is claimed that this peculiar combination enables a deep cut to be taken without glazing the wheel. In Bollman's emery grinder the table carrying the work is traversed beneath the wheel by a pinion working in a curved rack, and drops slightly during the return stroke, so that the work is clear of the wheel. The slide bars of locomotives are finished by being ground in a machine like a small planing machine, but having, instead of a cutting tool, a revolving emery wheel.

Any desired form may be given to the face of an emery wheel by turning it with a black diamond tool. In some places the brasses for cars are finished by being passed over an emery wheel with a semicircular face. Emery wheels with rounded profiles are also used to a considerable extent for grinding the flutes of taps and reamers. The Brady Manufacturing Company, of New York, has lately made a machine in which emery wheels are used to shape the ends and joints of pitch links. The rough links are dropped into a revolving chuck plate, which brings them successively into three separate emery wheels, by which they are finished at the rate of sixty links per minute. Another application of emery wheels with moulded edges is shown in Fig. 15, which is a machine made by Slack's Emery Wheel Company for cleaning out the teeth of wheels. The emery wheel is turned to the shape of the space between the teeth, and revolves in a small headstock, while the wheel, or pinion, being operated on is moved vertically in front of it by means of an eccentric motion, and at the end of each stroke is turned automatically through the space of one tooth. These machines are exclusively used by makers of textile machinery, and will clean from fifteen hundred to two thousand teeth per hour. Space does not permit a detailed description of all the various purposes to which solid emery wheels are now applied, but they are largely used by agricultural implement makers and by manufacturers of hardware and fireproof safes, and in the construction of cotton machinery. In some places the faces of pulleys, instead of being turned, are ground to the proper form in machines using emery wheels; and solid wheels of emery or corundum are now generally used instead of copper or lead laps for grinding hardened spindles and bushes in the lathe. Where the work only requires to be polished, or buffed, wooden wheels covered with soft leather and coated with emery are used, or sometimes emery belts are employed. At a textile machine

factory at Manchester the small shafts and rods are polished by being moved lengthways between rapidly running belts covered with emery; and at the same works the scrolls for self-acting mules are ground by an endless rope well supplied with emery and oil.

The cleanliness of emery wheels and their quick cutting character compared with natural grindstones render them convenient for sharpening tools. In America they are used to a considerable extent for sharpening saws, mill picks, paper-cutting knives, &c. They are now coming into use in this country for grinding lathe tools, drills and shear blades, and are found to impart a better edge to the tool than a grindstone. In Van Haagen's twist-drill grinders the drill is placed in a chuck that presents it at the proper angle to the edge of the wheel, and by an ingenious link connection the same movement of the handle for turning the drill round also gives the proper motion for backing it off behind the cutting lip. A small centrifugal pump keeps the wheel supplied with water, which is prevented from flying off by a hood that covers the wheel, except at the cutting point. A similar arrangement is used in the Universal Tool Grinders of Thompson, Sterne, and Company. One of these machines is shown in Figs. 16 and 17. It will be seen that the centrifugal pump is placed at the back of the machine, and is driven from a pulley on the counter-shaft. The safety grinding ring used with these machines is shown in section in Fig. 18. The sides of the emery ring are gripped between two washers with dovetail grooves in them, which would keep the pieces in position should the ring break. Corundum, which is a pure form of emery, and a harder and sharper abrasive than the emery of commerce, is used where it is important that the wheel should remain of the same diameter and shape. Morton Poole's system of grinding chilled calender rolls is an instance of the application of corundum wheels; there are several peculiar features about this process of grinding, and an extremely accurate result is obtained.

Tools of Detrusion and Penetration.

The principal tools that come under this head are punching and shearing machines. Theoretically the operations of punching and shearing are identical; but the term punching is generally taken to mean the production of a hole in the material, by the removal of the metal in the form of a blank; while in shearing, the material is separated into two pieces.

The mechanism of an ordinary punching or shearing machine is comparatively simple, and consists only of suitable gearing to impart a reciprocating motion to the punch or shear blade. In the old lever punching and shearing machines, which may still be found at work in many shipyards, a cam lifted the long arm of a lever, the short end of which moved the punch or shear blade. These took up a good deal of room, but were otherwise very efficient. Machines on this principle, but arranged in a more compact form, are extensively used in the United States at the present day.

Most machines now made are arranged so that punching or shearing may be performed by the same machine. In the small sizes the shear blades are placed above the punch, but in large machines the punch is at one end and the shear blades at the other; or, in some cases, the machines are constructed so that the punch and the die can be readily removed and shear blades substituted. In the majority of machines used in this country the rams carrying the punch and shear blades are worked by cranks. In one of the most common forms of machine the rams move in slides at the opposite ends of the machine, and are actuated by cranks at the end of a horizontal shaft, which is driven by gearing at the top of the machine. In De Bergue's punching and shearing machines the punch and shear blades are attached to the ends of the opposite arms of an inverted T-shaped casting that turns on a pivot at the junction of the arms, which are strengthened by being webbed together. This casting has a rocking motion imparted to it by a crank pin moving in a slot at the upper end of the vertical arm. Of course, in this case, the punch and shear blade move in the arc of a circle, but owing to their limited range of movement, and to the position of the fulcrum, this is immaterial. The larger sizes of punching and shearing machines are usually worked by a separate steam engine fixed to the frame, and supplied with steam through a pipe; or in some cases the machines are worked by hydraulic pressure, in many respects a convenient plan, as the machines are simple, and great power may be obtained without the use of gearing. As the machine is put into communication with the accumulator by merely opening a valve, the descent of the punch is entirely under the control of the attendant, doing away with the liability of the holes getting punched in the wrong places. It is true that most machines are fitted with a disengaging motion for the punch; but even then, if the work be heavy or awkward to handle, it often happens that the punch descends before it has been placed in the proper position. To obviate this, automatic tables to carry the work are sometimes

used. In this case the work is fixed to a table which is moved by a self-acting motion in front of the punch between each stroke, and provision is made for altering the pitch of the holes by means of change wheels. Jacquard and multifarious machines have been contrived for punching a number of holes simultaneously, and have been used in the construction of several large iron bridges. In Roberts's Jacquard punching machine, an arrangement, similar in principle to the Jacquard apparatus of a loom, selects the punches that are to operate at each stroke of the machine.

Holes of any desired shape may be punched in a machine by punches and dies of the proper form; thus the holes in the ends of rails are punched oval to allow for expansion, and oblong punches are used for punching out locomotive frame plates and similar work. The hole in the die is usually made slightly larger than the punch; this relieves the strain on the punch and causes the hole in the work to be conical; but as most punched holes are intended to be filled with rivets this is rather an advantage. The amount of taper given to the hole in the work depends on the difference between the diameters of the punch and of the hole in the die. A good formula for this clearance is, the diameter of the die-hole = diameter of the punch plus $\frac{1}{5}$ the thickness of plate.

It has already been said that the operations of punching and shearing are in theory the same. In a machine made some time ago for punching unusually large holes, the punch was annular, and was in reality a shear blade bent round into a cylindrical form; the severing operation commenced at one side and gradually extended right round. This gradual scissors-like action is obtained in ordinary machines by making the edge of the upper shear blade at an angle with the lower one, so that when it descends the shearing action begins on one side and extends across to the other. The width of plate that can be operated on depends on the depth of gap in the machine. To enable bars and long rods to be cut, the shear blades are sometimes placed at an angle with the frame of the machine, so that any length of bar may be passed through. Shearing machines with circular cutters are in some cases used for the lighter kinds of work. The cutters in these machines are circular disks of steel, made slightly conical, and fixed on the ends of revolving shafts, which are adjusted so that the edges of the large ends of the cutters just meet.

Tools of Inflection.

In this division come such tools as plate-bending and straightening rolls, armour-plate presses, garboard strake bending machines, flanging machines, jimcrows, and straightening presses. Plate-bending rolls are used by boiler-makers and shipbuilders for bending plates to a curved shape to form flues, boiler shells, or masts. In the ordinary construction of machines there are three rollers, two of which are driven by gearing and revolve in fixed bearings in the frame, and a third one, placed above midway between the two, is capable of being raised and lowered by screws under the control of the attendant. The plate to be bent is passed in alternate directions through the machine, and every time the bottom rolls are reversed the top one is screwed down, and the operation repeated until the plate attains the required degree of curvature. If the plate be bent round into a cylinder, so that the edges meet, it is evident that the only way to take it out of the machine is to slide it endways off the top roll; to enable this to be done the bearing at one end is made movable, so that the end of the roll can be left clear. There are several plans by which this may be effected; a convenient arrangement is shown in Figs. 19 and 20, which illustrate a set of plate-bending rolls made by Messrs. Grant and Macfarlane of Johnstone, near Glasgow. It will be seen that the upper part of the frame carrying the bearing and elevating screw is made in the form of an arch, and is attached to the lower part by two bolts; when necessary, one of these bolts may be removed, and the top frame swung clear round on the other. Bent plates may be straightened in machines of this kind by running them through the rolls with the top roll set to neutralise the existing curves.

Angle iron, T iron, and bulb iron may be bent in the same way as plates if grooves of the proper shape are turned in the rolls; but in the machines usually employed for this purpose the works are placed vertically, and project clear of the frame. In the machines for bending garboard strakes (the garboard strake is the line of plates next the keel of a ship), the plate to be bent is clamped to a table, and the bending roll brought to bear upon it by a powerfully geared quadrant at each end. Machines for flanging and preparing the edges of plates are now generally used in the best boiler works, and not only effect a considerable saving of time, but turn out cleaner work than that done by hand.

For circular work, such as cylindrical flues or rings, the most rapid way of forming a flange is to give a rotary motion to the

work, and deflect the edge, by bringing rollers or guides to bear upon it in much the same way that raised sheet metal ware is spun up in the lathe. In Hanson's flanging machine, used in several large boiler works in the North of England, the work is gripped in a self-centering chuck of large diameter, placed at an angle with the bed of the machine, and as it revolves the edge is acted on by a roller mounted on a segment controlled by worm gearing. Where the work is irregular, and cannot be operated on by a rotary machine of this kind, the flanging is usually performed by pressing the work between dies. Dies made in the form of a hollow ring, on the plan of M. Piedbœuf, of Yupille, Belgium, have considerable advantages over the old form of solid die, both in first cost and convenience in working. In the machines made by M. Piedbœuf the dies are worked by means of a screw. In Tweddell's hydraulic flanging machines a similar arrangement of hollow dies is employed, except that the movable die is fixed on the plunger of a hydraulic press.

Tools of Contusion and Compression.

The Author has placed the fifth and sixth sections together, as there are many operations in the forging and working of metal in which a compressive action may be used as an alternative to contusion or hammering. In the fifth division the most important tool is certainly the steam hammer. It is difficult to imagine what the state of affairs would now be if the steam hammer had not been invented. Such work as the stem and stern posts and propeller shafts of modern steamships could not well be forged by any other means; without the aid of the steam hammer heavy ordnance would never have attained its present size; and the development of the mechanical arts must have been checked in many directions. It is well known that Nasmyth had the idea of the steam hammer in his mind some time before he actually constructed one, and it was not until after a visit to Creusot, in France, where he found that his idea had leaked out, that he commenced to make them at Patricroft. The original form of steam hammer was similar to many that are made in the present day. The cylinder was set on the top of cast-iron frames, which formed guides for the tup, and spread out sideways below to give room to turn the work on the anvil, and the steam only acted to raise the piston, the tup falling by its weight alone. Condie's hammer, in which the cylinder acted as a tup and moved on a fixed piston, was another early arrangement. In Naylor's and many other hammers, the steam acts upon both sides of the

piston; and a much greater number of blows per minute can be given than where the fall of the tup is due to gravity alone. Of late years wrought iron has been used to some extent in the place of cast iron for the framing of steam hammers, particularly in cases where it is desirable to have a clear headway beneath the frame. A hammer with wrought-iron framing, made by Messrs. Thwaites and Carbutt, of Bradford, is shown in Fig. 21. In this arrangement the cylinder and guides for the tup are mounted on a hollow box girder, supported by wrought-iron standards set sufficiently far apart to allow a clear passage on each side of the anvil block. In Morrison's system of steam hammers the piston, piston rod, and tup are all forged in one piece, and in this case no guides are applied to the tup, but the piston rod is guided by being prolonged through the top cylinder cover, and is prevented from turning by a flat place formed in the gland; the upper part of the piston rod is also used to work the valve motion.

The most suitable arrangement of automatic valve gearing for steam hammers is rather a difficult question to decide. With a great deal of work it is of primary importance that the hammer should fall freely on the work without being checked by the premature admission of steam on the under side of the piston; and as the thickness of the work on the anvil varies after each blow, and the amount of variation is uncertain, it is impossible to apply any regular progressive feed motion to the tappets, and the gearing must accommodate itself to the variation, whatever it may be. This difficulty is overcome in some arrangements by connecting the valve motion to a swinging bar, which is set in motion by the descent of the hammer, and acquires sufficient momentum to continue its movement and open the valve after the hammer has stopped. In large steam hammers the anvil blocks are kept entirely distinct from the frames; they rest on solid foundations that extend a considerable depth into the ground, and are costly to construct. To obviate the necessity for these heavy anvil blocks and expensive substructures, Mr. Ramsbottom devised a duplex steam hammer, in which the work is operated on by two hammer-heads moving with equal force in opposite directions. In this case the hammers are horizontal, and the valve gearing of the two cylinders is arranged to act simultaneously. Power hammers, in which the tup is driven by a crank with an interposed spring of air, steel, or india-rubber, are now used for forging light work, particularly in the United States, where they are employed for doing a great deal of work that would, in this country, be done in Ryder's forging machine. These

machines are well known; an illustration of one of them is given in Figs. 22 and 23 to show the general arrangement. Several small plungers set in a line in the upper part of the frame, which are driven rapidly up and down by cranks on a shaft running about eight hundred revolutions per minute. Swages of various forms can be attached to the bottom of these plungers, and corresponding swages fixed to small rams that have a vertical adjustment by means of screws passing through the bottom of the frame. The peculiar combination of blow and push with which these machines operate seems better adapted than anything else for producing clean, sharp work, without cracking or splitting at the edges. In all the large small-arm and sewing-machine factories and establishments of a similar kind in this country, these machines are employed for forging small work of a circular cross section, while the irregular-shaped pieces of work, such as the breech blocks and trigger guards of rifles, are forged in dies, either under steam or drop-hammers; the principle in both cases being the same. One of the dies is attached to the tup, while the other is fixed to the anvil, and adjusted sideways, so that the recesses in both dies exactly coincide. When the hammer descends, the hot metal is driven into all the cavities of the dies, and any excess is forced out at the side in the form of a fin, which is afterwards cut off in a trimming press. The operation of machine riveting is an instance where a compressive action may be regarded as alternative to a percussive one. In the steam riveter, familiarly known among workmen as the "iron man," the rivet is closed by a percussive action. In the power riveters driven with a crank or cam the rivet is closed by a combination of percussion and compression. In hydraulic riveters the action is mainly compressive; although by using a differential accumulator in which the loaded plunger has a long range of movement, compared with the capacity of the cylinder, the momentum of the falling plunger may be made to act in much the same way as a fly-wheel, and may cause a pressure of 20 tons at the commencement of the stroke, to rise as high as 40 tons at the moment of closing the rivet. An incidental advantage of the use of hydraulic power for actuating such machines as riveters is the facility it gives for the employment of portable tools, as with the concentrated form in which the power is transmitted only a small and consequently light machine is required to utilise it. In Mr. Tweddell's system of portable riveters, the water under pressure is conveyed through flexible copper pipes to the machine, which is hung by a chain from the jib of a crane or an overhead traveller. An arrangement of this

kind was adopted in the erection of the Primrose Street bridge of the Great Eastern railway.

CONCLUSION.

In conclusion, the Author begs to express his best thanks to the many engineers, both abroad and at home, who have so kindly given him information about their machines, and afforded him facilities for visiting their workshops. Space does not permit of any speculations as to the future development of machine-tools. Minor improvements in such details as tool-holders, chucks, automatic feed motions, &c. are constantly being made. A novel arrangement of electro-magnets for holding the work in lathes and planing machines is now being tried in one or two machine shops; but it is hardly likely to prove a success, except in a few special cases. Electric stop motions are now used in certain classes of textile machinery, and an arrangement of a similar nature might perhaps be adopted in those machine-tools where it is necessary to stop or reverse the machine with great precision. No doubt improvements in machine-tools will continue to keep pace with the times, as progress in constructive engineering and progress in machine-tool making are inseparably connected, and act and react upon one another; the requirements of the manufacturing engineer leading to the production of new machine-tools, and the existence of improved tools permitting new combinations of constructive material.

This communication is illustrated by diagrams and photographs from which Plate 5 has been compiled.

No. 1,533.—"The Egremont Ferry Landing." By WILLIAM CARSON, M. Inst. C.E.

THIS ferry is situated on the Cheshire side of the river Mersey, opposite Liverpool. The distance from the shore to a point which would afford a sufficient depth of water for the ferry steamers at all states of tide was found to be 750 feet; but the Conservancy refused to sanction the erection of fixed works with a greater extension into the river than 360 feet. The character of the Mersey, and the peculiarities of the site not being considered favourable for dredging or excavating operations, so as to provide deep water up to the point to which the fixed works could be carried, it was obvious that some movable arrangement must be resorted to if the ferry landing was to be made suitable for continuous traffic. Under these conditions the Author was called upon in 1874, by the Wallasey Local Board, the owners of this and adjacent ferries, to design the necessary works, and they were finally constructed as follows.

A pier 275 feet long and 35 feet above low-water level, composed of two lines of wrought-iron lattice girders of the ordinary type, is supported at intervals of 35 feet by cast-iron piles 1 foot in diameter. A timber flooring is laid on the top of the girders, with an ornamental fence formed of cast-iron standards carrying three gas-pipe rails at each side.

At a distance of 85 feet beyond the outer end of the pier a dolphin is erected, composed of two groups of wrought-iron columns filled with concrete up to high-water level, arranged tripodwise; these are braced together, and are connected overhead by a plate and angle arched box girder. A timber fence of American rock elm in whole balks, served with heavy convex wrought-iron plates, is secured to the river face of the dolphin to take the chafe of the ferry steamers when they approach or lie at the pier.

The dolphin is connected with the pier by a bowstring wrought-iron girder bridge 80 feet long, hinged at its point of attachment to the pier, and supported at its outer end by two hydraulic coupled rams fixed within the dolphin, by which the height of the bridge can be adjusted by the attendants to the varying levels between high water and half tide, when the ferry steamers can approach the dolphin.

The passengers land or embark over a drop gangway of substantial construction attached to the outer end of the bridge by a crosshead and pin, to provide for vertical and lateral adjustment. This gangway is worked by a small hydraulic ram placed underneath the floor, and in the line of the axis of the bridge. The ends of the chain by which it is raised and lowered are secured to the handrail standards of the gangway, and the "bight" is passed over a sheave in the head of the ram, so as to allow of the lateral adjustment of the gangway on the deck of the steamers without interfering with the action of the ram.

Underneath the pier, and extending for an equal length into the river-bed beyond it, a masonry slipway of ashlar blocks set in hydraulic mortar has been constructed, with an inclination of 1 in 43. Upon the slipway three lines of cast-iron trough rails are laid flush with its surface.

A movable carriage, 370 feet 6 inches long, traverses the slipway, its position being adjusted according to the tide level between half tide and low water, and *vice versâ*, so as to afford a sufficient depth of water for the ferry steamers to approach the outer end. The carriage, which runs upon heavy cast-iron wheels fixed to wrought-iron shafts from 3 inches to 6 inches in diameter is formed of two lines of continuous wrought-iron lattice girders 4 feet deep, having a timber roadway on the top, and the planking is open spaced to obviate the risk of the carriage being lifted by the sea in rough weather. At its outer end it is fitted with substantial elm rubbing pieces served with wrought-iron plates, and the ferry steamers are made fast to it while landing or embarking passengers by suitable attachments. The weight of the carriage is 80 tons.

The movements of the carriage on the slipway are controlled by winding gear placed within the dolphin above the level of high water. A Brotherhood's three-cylinder water engine, having cylinders 5¼ inches in diameter, with a length of stroke of piston of 4 inches is geared up in the ratio of 25 to 1, to a cup drum. Over this drum the hauling chain passes, and the ends of the chain are secured at the extremities of the carriage. The engine is fitted with reversing gear, and the carriage is capable of being moved in either direction.

The mode of landing is as follows:—Between the times of half tide and high water, and *vice versâ*, the ferry steamers, which are from 150 tons to 350 tons, builders' measurement, make fast to the dolphin, and the bridge being at a suitable level, the gangway at the end of the bridge is lowered on to the steamer's deck. The

passengers proceed up the bridge on to the pier and so to the turnstiles in the ferry station on shore.

Between the times of half tide and low water, and *vice versâ*, the ferry steamers make fast to the outer end of the movable carriage, which has been previously adjusted, as regards its position upon the slipway, so as to provide a sufficient depth of water for them. The passengers proceed along the carriage until they reach the dolphin, where they find the bridge lowered to nearly the level of the deck of the carriage; and the gangway, which previously made the connection between the bridge and the steamers, now connects the bridge and the carriage; and so they gain the pier as before. There is thus provided a continuous roadway to and from the steamers at all states of the tide. The movable carriage is housed underneath the pier when it is no longer required; and it is capable of being automatically regulated so as to reach that point when there is a sufficient depth of water at the dolphin for the accommodation of the ferry steamers.

The upper portion of the river beach at the site of the ferry is formed of sand and shingle which is liable to be shifted on to the slipway by the action of the sea. Power to actuate the carriage downwards as well as upwards was therefore necessary, and was provided as already described. But with a view to economy in working, and to obviate this necessity, unless under exceptional circumstances, a sluicing chamber was constructed at the head of the slipway, which by cross paddles, and at the discretion of the attendants, thoroughly scours the slipway and adjacent sandbanks. The sluicing chamber has a capacity of 200,000 gallons. It is filled by each tide, and is discharged by the paddles at low water. This arrangement has proved successful, few occasions having arisen in which power, beyond that of gravity, has been necessary to project the carriage down the slipway.

The accumulator is fixed in a building on the wharf. The ram, which is 14 inches in diameter, has a lift of 13 feet 6 inches. A double-acting pump 3½ inches in diameter, with a length of stroke of 16 inches, actuated by a high-pressure direct-acting engine, the cylinder being 10 inches in diameter, working with a boiler pressure of 50 lbs. per square inch, supplies the accumulator against a dead-weight pressure of 800 lbs. per square inch. A duplicate engine, including boiler and pump, is provided in the engine house; and, to ensure safety in emergencies, a powerful crab winch with a steel-wire rope, worked by a capstan and handspikes, is erected in a suitable position on the slipway; by this winch

the carriage can be worked by six or twelve men; the rope being attached direct or over a snatch pulley fixed to the carriage, according to the strength which may happen to be available. When the ferry is closed at midnight, the carriage is housed under the pier and braked. The bridge, having been lifted level, is slung and shackled to chains depending from the arch of the dolphin; and the rams are then lowered into their cylinders so as to be safe from damage.

The exposed position of the hydraulic machinery renders its protection from frost impossible by ordinary methods. Accordingly the Author, after much experiment, decided upon using a mixture composed of 1 part of crude brown glycerine of a specific gravity of about 1·125 to 4 of water; with this the whole system is kept charged during the winter. Return-pipes convey the fluid after use back to the cistern which supplies the pumps. A perfect mechanical mixture of the fluid was found to be necessary, and is accomplished by introducing a steam jet into the bottom of the mixer; the necessary quantity of water being the result of the condensation of the steam so admitted. The mixture thus obtained is perfectly liquid at a temperature of 16° Fahr.

For the protection of the pier a chain boom has been moored at each side of it. The chain is supported above the surface of the water upon wrought-iron buoys moored at intervals of 35 feet. The boom has been very serviceable in keeping river flats and other small craft clear of the works.

The whole of the works described were constructed at a cost of £12,000, and they have been successfully used since March 1875. The cost of the ferry station, containing suitable offices and waiting-rooms, has been £2000 in addition to the above amount.

The stage attendants are ordinary seamen, whose duty it is to take the ropes from the steam vessels. Owing to the simplicity of the arrangements, they are able to manipulate both the bridge and the carriage satisfactorily.

The Paper is illustrated by drawings from which Plate 6 has been engraved.

No. 1,555.—"The Drainage, Irrigation, and Cultivation of the Albufera of Alcudia, Majorca; and Application of the Common Reed as a Material for Paper." By HENRY ROBERT WARING, M. Inst. C.E.

A CONSIDERABLE amount of capital has been invested in the drainage of marshes on the east coast of Spain, hitherto with unsatisfactory returns. This has also been the case with the Albufera of Majorca, an important example from the nature and completeness of its drainage and irrigation works, the large area now reduced to first-class cultivation, and the remarkable improvement which the drainage has effected in the sanitary condition of the adjoining district, the population of which is rapidly increasing.

This marsh was purchased and its drainage undertaken by the Majorca Land Company of London. The total area of the reclaimed land is 5,100 acres. Its northern extremity reaches nearly to the town of Alcudia of 1,500 inhabitants. Sand hills fringing the bay of Alcudia form its boundary for upwards of 5 miles on the east; on the north and south it is bounded by hill farms and pastures, and on the west for a length of 3 miles by the so called "Marjales" of La Puebla and Muro, towns of about 5,000 and 4,000 inhabitants respectively, which are situated 3 miles from the border of the Albufera. The Marjales referred to are low lands now in a high state of cultivation, irrigated by "norias" or by hand, and producing for the most part two crops yearly; their area is upwards of 3,000 acres. The works for the drainage and irrigation of the Albufera have been executed from the designs and under the direction of Mr. J. F. Bateman, F.R.SS. L. & E., President Inst. C.E. They were begun in 1864 and terminated for the most part in 1871. Such works as further experience of the climate and influential torrents showed to be advisable have since been executed under the same direction. The drainage works provide for the carriage through the property and discharge to sea of two of the principal torrents of the island, which rise some leagues away in the mountains 5,000 feet above sea level. These torrents are carried in embanked channels; they form a junction in the Albufera, and flow united to the sea in a watercourse 164 feet wide and nearly 10 feet deep from the top of

the embankments. The outlet to the sea is protected and preserved by two jetties of rockwork carried into deep water.

The copious springs on the borders of the Albufera, the water from the Marjales, and from more local torrents, are also carried in embanked canals and discharge into the main watercourse near the sea through automatic flap-gates. A portion of this water serves for irrigation.

The drainage of local rainfall, and of water derived from filtrations on the property, is effected by four steam engines, one of 40 HP. and three of 25 nominal HP., working scoop wheels. These engines are placed in pairs at stations upwards of 2 miles apart. The largest engine also serves to raise water for irrigation. The drainage water elevated by the scoop wheels finds its way to sea from one station, through the main watercourse, and from the other by an independent embanked channel.

The main irrigation canals constructed of masonry almost surround the property, and feeders and carriers also in masonry are capable of affording irrigation to upwards of one-half of the property; the available supply of good water for this purpose amounts to 65 cubic yards per minute in dry seasons. By the construction of upwards of 30 miles of roads within the Albufera, means of communication have been afforded between all parts of the property and the neighbouring towns, as well as to the harbour of Alcudia.

The surface soil of the Albufera in general consists of decomposed vegetable matter mingled with mud deposited by the periodical inundations to which the Albufera was formerly subject. The depth of this mixture was much greater at the commencement of the works than now, the result of drainage and further decomposition promoted by cultivation having been to reduce its thickness, which is at present from 18 inches to 2 feet. The greater portion of the surface of the Albufera has subsided, from the causes mentioned, from 18 inches to 2 feet since 1868.

The subsoil is mostly a whitish mixture of calcareous and argillaceous deposit, which, owing to the diminution in the thickness of the layer of vegetable soil, can now be mixed with the latter by deep delving. The layer of vegetable soil is wanting over an area of a few hundred acres, the sites of former lagoons. There are also a few hundred acres of poor sandy soil, some small patches of flat rock of recent formation, and former sand hills now transformed into soft rock; but all these classes form a very small portion of the Albufera.

As early as 1865, while the drainage was yet incomplete, the

cultivation of cotton was attempted by the Majorca Land Company, principally in the sandy districts and on the borders, where the ground was sufficiently firm to allow of steam cultivation. A small quantity of cotton of excellent quality was produced, but the situation open to the north-east and east was too exposed to the violent winds from these quarters to allow of the plant being cultivated with success. The idea was therefore abandoned, and the land thus prepared was let to tenants who merely took advantage of the cultivation bestowed on it by the Company, soon leaving it in an unproductive condition. This land was firm but poor, allowing of ploughing, but requiring much manure.

In 1868, the drainage being sufficiently completed to permit cultivation on a large scale, a system of subvention recommended by intelligent natives was adopted by the Company with the view of attracting labour and capital. This system, which then appeared likely to place the property in a paying condition as soon as possible, was as follows:—

The tenant engaged to delve the surface of his entire holding to a depth of 1 foot 4 inches, to break the clods, and burn, and perform, in fine, all the labours of first-class cultivation as practised in the neighbouring Marjales. In return the tenant was to receive from the Company £2 7*s.* per acre, and was to occupy the land for two years free of rent.

Almost the whole property was cultivated on this system between 1868 and 1872, and fine crops of oats, the only crop at that time thought possible by the tenants, were produced. But the tenants were speculators, too few in number, and holding areas far too large for their means. They consequently were unable or unwilling to risk the expense of further cultivation, which indeed could never be repaid by successive crops of oats alone, and for the most part they gave up their lands on the expiration of the term of free rental or soon after, and few good permanent tenants have been obtained by this system.

In 1871 the total number of tenants paying rent in cash or in kind was sixty-six; the total corresponding area of land under cultivation was 1,444 acres, and the average area per tenant 21·87 acres.

In 1872 the area paying rent was much increased by the termination of many free leases. The number of tenants was one hundred and seventy-two, the corresponding area 2,467 acres, and the average area per tenant 14·34 acres. Oats still remained almost the only product, as the tenants were unwilling to risk the expense of cultivation necessary for more valuable crops. The

condition of almost the whole area nominally cultivated was lamentable, the purely superficial cultivation which it was receiving having served to foster the growth of weeds, especially of the common reed, which overpowered the crops of 1873.

In this year the Company recognised the advisability of proving at its own expense that the land was capable of producing more valuable crops than oats; that methods which allowed speculators to gain by the labour of others were not advisable; and that tenants should be obtained, if possible, for areas so small as to be cultivable by themselves and their own families, in a similar manner to that which obtains on the Marjales, the quantity and quality of work done under such circumstances being much superior to that of hired labour. No help was to be expected from the immigration of tenants from beyond the limits of the towns of La Puebla, Muro, and Alcudia.

The inhabitants of the island in general are unaccustomed to hand delving, and unable to use the tool employed for this purpose by the men of La Puebla and Muro; besides which throughout the island the demand for agricultural labour is equal to the supply.

It must be observed that the yielding nature of the soil, and the proximity and number of drains, render steam cultivation or even deep ploughing impossible over the greater part of the property, and that the rapid and unceasing growth of the common reed renders the production of permanent grasses out of the question for years to come, while vastly increasing the amount of labour necessary on these lands, thus limiting considerably the area cultivable by each tenant.

In 1873, the subvention system having failed in procuring suitable tenants, the Company commenced cultivation on its own account in a thorough manner for hemp and beans especially; at the same time new tenants were only admitted for small holdings, and for leases of six years.

The result of the Company's crop of beans and hemp in 1874 was such as to change completely the opinions of the tenants, and to induce a considerable influx of new tenants for small areas, with the avowed purpose of cultivating the land for hemp. From this time the number of tenants has continued steadily to increase, and the class of cultivation to improve, the rotation generally followed being a threefold course—hemp, beans, and oats or barley—the last being sown instead of wheat, which as yet does not thrive upon the Albufera. The area under cultivation decreased from 1872 to 1876, when it was at a minimum; since then it has

increased. The average area occupied per tenant has probably now reached a minimum. For the year 1877 the total number of tenants paying rent in cash or in kind was four hundred and eighty-three, cultivating 857 acres of land, the average area per tenant being 1·77 acre. It now seems that most of the surplus labour of La Puebla flows into the Albufera in the shape of tenants or sub-tenants, the former being permitted to sub-let portions of their holdings on the same terms as they themselves hold them. Comparatively few tenants come from either Muro or Alcudia, and the tenants from Alcudia are only fit for cultivating with the plough on the poorer lands.

The construction of two villages has been commenced by the Company with the view of attracting settlers from the more distant towns of Pollensa and Buger, 7 and 5 miles respectively from the border of the Albufera, and from which a small number of tenants are derived. The population of Pollensa is nearly 9,000, and its parish so small in proportion to the population that a large part of the parish of Alcudia is rented and cultivated by Pollensinos.

Even under favourable circumstances, much time will be required to develop to its full extent the property of the Albufera. Supposing the average area of land cultivated per tenant be ultimately 3½ acres for the vegetable soils, and allowing for a larger area for the poorer lands, the number of tenants requisite to cultivate the whole available area would not be less than twelve hundred, representing a purely agricultural population of between five thousand and six thousand souls. This expansion could not take place until the reeds were in a great measure exterminated; but although this is being effected by good cultivation and hemp crops, it will take a long time to obtain the twelve hundred tenants. If in the meantime any profitable application can be made of the reed, *Phragmitis communis*, which grows so luxuriantly over thousands of acres, it would perhaps be better policy to limit the area under cultivation. The reed mentioned has hitherto served either as forage for cattle when very young, or for burning land in the "Marjales" when at maturity. Several thousand tons of it have been yearly extracted from the Albufera for the latter purpose.

It occurred to the Author that this plant might contain a fibre suitable for making paper. After some preliminary experiments by persons acquainted with the paper manufacture, who augured favourably, in October 1877 trials of the whole process of paper-making with this reed were carried out under the direction of an experienced Belgian paper-maker.

Two separate trials were made with reeds in different stages of growth and dryness as follow:—

TRIAL 1.

		lbs.
Reeds cut before maturity, two months previous to trial thoroughly dry, broken in hemp-scutching machine, and boiled for eight hours with 15 per cent. weight of caustic soda, in a rotative boiler, with 60 lbs. pressure of steam per inch		950
Resulting fibre worked into paper at a rag paper mill as for foolscap and cigarette paper—	lbs.	
Result—Paper	439	
Dry pulp	6	
	—	445

$$\text{Yield} = \frac{445}{950} = 46\cdot84 \text{ per cent. of the raw material.}$$

TRIAL 2.

		lbs.
Reeds cut quite mature and passed immediately through a straw-cutting machine, without drying, and boiled forthwith as in Trial 1, then worked up in same rag mill as for foolscap.	Raw material	720
	lbs.	
Resulting weight of paper	183	
" " dry pulp . . .	40	
	— Yield =	223

$$\text{Yield} = \frac{223}{720} = 30\cdot97 \text{ per cent. of the raw material.}$$

The quantity of water contained in the reeds submitted to the last trial must have been very large. Attempts to bleach the pulp were unsuccessful in the first trial, and only partially successful in the second; the pulp was too much diluted. Subsequently the fibre has been bleached perfectly. Specks in all the samples are pieces of the outside fibre (not knots) which have resisted the disintegrating action of the cylinders used for tearing rags, and show that a different class of machinery is required for making fine papers from this new material. The strength of the paper made entirely from this fibre is very great, and the fibre is particularly fine and elastic.

The Author is unable to compare the cost of the manufacture of reed paper with that of straw or esparto paper, but the quantity of raw material is so great that a manufactory producing 3,000 tons of paper yearly would certainly not exhaust the supply of the Albufera. Good roads and navigable canals intersect the reed

producing district, and connect it with the harbour of Alcudia. The cost of 1 ton of dry reed delivered at any spot on the Albufera would not exceed 8 shillings; and it could probably be delivered in an English port for £4. Should the proposed application of the reed be successful, the necessities of financial enterprise may after all be found to harmonise with the requirements of humanity in the drainage of the pestilential marshes of the Mediterranean.

No. 1,566.—"Description of the Excavating Machine, or Steam Navvy, with the Results of its Use, on the West Lancashire Railway." Communicated by CHARLES DOUGLAS FOX, M. Inst. C.E.

GENERAL DESCRIPTION.

IMMEDIATELY after receiving possession of the land embracing the deep part of No. 9 cutting, two trial holes were sunk from the surface down to the formation level. It was thus found that the material to be excavated was a stiff brown clay throughout, free from large stones, thereby inducing the belief that it might be worked by machinery, which up to this time had been almost exclusively employed in sand, silt, loose shale, or soft free clay. After visiting two or three of these machines, Messrs. Barnes, Squire, and Co., of Southport, the contractors (who have kindly collated the following facts), put themselves in communication with the makers (Messrs. Ruston, Proctor, and Co., of Lincoln), at the same time suggesting the strengthening of certain parts. The result was the purchase on the 12th of June, 1877, of a steam navvy, Plate 7, "consisting (as the makers describe it) of a rectangular truck, supported on four wheels, carrying the engine and boiler, wheel gear, fixed post, and jib. The engine is of the vertical type, of 10 HP. (two cylinders), and gives motion, by a pinion upon its crank shaft, to the main spur wheel upon the main hoisting drum shaft, from which the motion is communicated to the drum for swinging the jib, and the drum for drawing the bucket back. The drum for swinging the jib has a reversing friction motion for swinging both ways. The bucket handle is regulated by hand wheel and chain pinion, which gives motion to a pinion at the top of the jib gearing, into a rack upon the bucket handle. The truck is provided with six strong screws, or lifting-jacks, for the purpose of steadying and taking the whole weight of the navvy when at work. The jib which carries the bucket handle is constructed entirely of plate iron, and strengthened with angle iron, as also is the fixed post and truck. At the bottom of the fixed post is a water tank for supplying the boiler. The bucket is of plate iron, and fitted with four steel pointed teeth, and a sharp steel nose where it first enters the ground. Improved propelling gear is also provided for moving the machine along the

rails by a self-acting arrangement of reversing tooth gear, which communicates the motion to the front axle by an endless chain. A corrugated iron roof covers the engine, and the whole of the working parts, except the jib gear."

Description of Working.

The dimensions of the cutting to be excavated were 30 feet wide at the base, slopes 2 to 1, greatest depth 22 feet, smallest depth 12 feet, length about 15 chains, contents about 45,000 cubic yards.

The "navvy" is placed upon the formation level of the cutting, on two lengths of large flat-bottomed rails, laid upon sleepers 12 inches by 6 inches deep, about 2 feet apart. A tramroad for empty wagons follows up the centre line behind the "navvy," and there is a road on each side the machine for filling wagons, parallel to the centre road, but at a level of about 3 feet above formation. The wagons have to be brought up to a position at right angles to the centre line of the machine, and directly under the bucket, for filling. The bucket describes a radius of about 20 feet, thus requiring a width of working room exceeding 40 feet across the cutting. This is secured by taking advantage of the slopes at the false level. The roads are connected at the mouth of the cutting by points, and close behind the "navvy" by jumps, so that all returned empties are passed up the centre road, and supplied to each side alternately by horses through the jump. When filled, they pass out down the side road to form a train at the mouth of the cutting. In this way two wagons can be filled in a few seconds over five minutes. The process of getting the earth by the machine bucket may be best described as paring the surface from the bottom to the top in a series of strips, about 4 or 6 inches deep, from the centre of the cutting to each side wagon, in the form of a basin, resembling the inside of a conchoidal shell. The man at the wheel regulates this motion, and may show great skill or otherwise in its guidance, as the more regular the action the less is the wear and tear of the machinery. When the bucket reaches the top, the driver jibs round to the wagon, drawing slightly in from the face by another motion at the same time, and directly the bucket is over the wagon, the wheel man pulls a string connected with a catch to the trap-door, or lid, at the bottom of the bucket, and the contents fall into the wagon. The catchman refastens the catch (having previously thrown back any lumps which roll in its

way), and the bucket returns and drops to the ground for another slice. Men in the gullet and on the slopes constantly cut out the little corners, which lie outside the basin or bucket radius. This is continued until the face becomes too far advanced for the bucket to reach, when the whole machine is moved onward by screwing up the jacks, pulling the rails forward, lowering it down again on its wheels, and the "navvy" then advances by its own locomotion to the position necessary for a fresh start, an operation which usually occupies about ten minutes. This moving of the machine requires to be done about four or five times a day, and at the close of a good day's work in a cutting, the "navvy" will be about 6 feet in advance of the position in the morning.

Cost.

	£.	s.	d.	£.	s.	d.
The net cost of this machine as described was				1,150	0	0
Duplicate parts were added as a provision for breakdowns, viz.:—One $\frac{3}{4}$-inch main chain; one $\frac{5}{8}$-inch swinging chain; one spur pinion; four adjusting screws and swivels for bucket; one bevel pinion for swinging gear; two rack pinions; two lengths straight rack; four steel ended teeth with fastenings; one 19-inch sheave pulley; two 10-inch sheave pulleys; four friction rollers; one slewing clutch; one travelling wheel; and two brass bushes for main drum, at an additional cost of . . .				27	0	6
Add carriage from Lincoln to Southport				41	8	1
" " Southport to cutting site, say . . .				11	11	5
This distance was about 8 miles, and the weight of the different parts amounted to about 35 tons. A tramway was connected with the railway at Southport, by which the machine was conveyed to within a few yards of its destination.						
Cost of machine on the ground				1,230	0	0
The fixing proved a tedious and expensive matter. The whole of the machinery arrived on the ground on the 19th of June, but the "navvy" did not commence regular work until the 17th of July, involving a cost in labour of fitters, carpenters, labourers, &c., of	49	19	4			
Add to this a proportion of stores, smiths' work, timber foundations, superintendence, &c., estimated at.	20	0	8			
				70	0	0
Total estimated cost ready for work . . .				1,300	0	0

Cost of Working.

From the 17th of July to the 31st of December the expenditure was as follows:—

	Days.	s.	d.	£.	s.	d.	£.	s.	d.
Wages:									
One engine driver . . .	126	6	0	37	16	0			
„ cleaner.	126	4	0	25	4	0			
„ stoker	126	2	6	15	15	0			
„ wheelman. . . .	126	5	0	31	10	0			
„ ganger	165	8	4	68	15	0			
„ pumper	126	3	0	18	18	0			
„ catchman	126	4	6	28	7	0			
Four gullet trimmers . .	420	4	3	89	5	0			
„ slope „ . . .	360	4	3	76	10	0			
One brakesman . . .	126	4	6	28	7	0			
Two platelayers . . .	242	4	0	48	8	0			
„ horses	330	5	0	82	10	0			
„ drivers	330	4	3	70	2	6			
							621	7	6
Stores:									
32 gallons oil		4	0	6	8	0			
127 lbs. waste		0	3	1	11	9			
21 lbs. tallow		0	5	0	8	9			
86 tons coal.		14	0	60	4	0			
Sundries, including smithy, say				2	17	6			
							71	10	0
Repairs:									
There have been about twenty breakdowns, but none of a serious nature. These have varied from a stoppage of one hour to two days, during which time the men have been made useful in lightening the cutting sides, and filling wagons by hand labour. Nine of these breakdowns have occurred through the fracture of the chain gear, which, however well greased, has to sustain a great amount of wear and tear. In one instance the drum had to be lifted, and a new bush inserted. In three or more instances, the catch at the back of the bucket lid got damaged by the shaft falling too quickly, and smashing the bucket against the pillar foot; the valves dropped off the spindle twice, and were once broken; the wheel shaft was bent once, the block check broke three times, &c., the cost being, say							25	2	6
Depreciation:									
This has been estimated at 25 per cent. per annum on the total outlay, say therefore 12 per cent. on £1,300							156	0	0
							874	0	0

At this cost the earth is delivered at the cutting mouth ready

to be conveyed to its destination. The following is a list of the wagons and their contents, so delivered:—

WAGONS FILLED by STEAM NAVVY in No. 9 CUTTING on the WEST LANCASHIRE RAILWAY from the 17th JULY to 31st DECEMBER, 1877.

—	Number each Month.		Contents per Wagon.	Number of Cubic Yards Excavated per Month.			Number of Days Worked.			Daily Average in Cubic Yards.		
	By Machine.	By Hand.		By Machine.	By Hand.	Total.	By Machine.	By Hand.	Each Month.	By Machine.	By Hand.	Each Month.
July.	613	..	3	1,839	..	..	12	..	..	153	..	..
	..	3	2½	..	8	..	..	1	..	..	8	..
	..	..	..	..	..	1,847	..	..	13	..	..	142
August.	1,386	..	3	4,158	..	..	16	..	..	260	..	..
	..	134	2½	..	335	..	..	8	..	..	42	..
	..	..	..	..	..	4,493	..	..	24	..	..	187
Sept.	1,841	..	3	5,523	..	..	20	..	..	276	..	..
	..	23	2½	..	57	..	..	1	..	..	57	..
	..	..	..	..	..	5,580	..	..	21	..	..	266
Oct.	1,276	..	3	3,828	..	..	15	..	..	255	..	..
	..	263	2½	..	658	..	..	10	..	..	65	..
	..	..	..	..	..	4,486	..	..	25	..	..	179
Nov.	1,029	..	3	3,087	..	..	13	..	..	237	..	..
	..	174	2½	..	435	..	..	9	..	..	48	..
	..	..	..	..	..	3,522	..	..	22	..	..	160
Dec.	1,258	..	3	3,774	..	..	17	..	..	222	..	..
	..	79	2½	..	298	..	..	4	..	..	74	..
	..	..	..	..	..	4,072	..	..	21	..	..	194
Totals	7,403	676	..	22,209	1,791	24,000	93	33	126	239	54	190

Number of days in the calendar for above period less Sundays = 165, the remainder being lost principally through wet weather.

Greatest number of wagons turned out in one day, September 28th and October 5th, = 123 × 3 = 369 cubic yards.

Actual measurement of cutting at the end of the year 24,964 cubic yards, which included a small quantity run out with barrows.

Thus, during the whole period quoted, 24,000 cubic yards of material have been turned out of the cutting at a total cost of £874, or say 8¾*d.* per cubic yard.

Had the cutting been worked entirely by hand labour in the ordinary way, it is estimated that the cost of production would have been as follows, taking the daily average of 190 cubic yards,

and the number of working days at 126. 190 cubic yards at $2\frac{1}{2}$ cubic yards per wagon = 76 wagons per day, say 11 sets per day; 7 wagons in a set, consisting of 2 gullet and 5 wing wagons, which would require—

		s.	d.	£.	s.	d.	£.	s.	d.
One ganger	at	8	4	0	8	4			
Ten gullet men	„	4	3	2	2	6			
Seventeen wing men . . .	„	4	3	3	12	6			
Two platelayers	„	4	0	0	8	0			
One brakesman	„	4	6	0	4	6			
Two horses	„	5	0	0	10	0			
Two drivers	„	4	3	0	8	6			
							7	14	4
Add stores, tools, &c., say							0	15	8
Thus the excavation of 190 cubic yards would cost about $10\frac{3}{4}d.$ per yard							8	10	0

Thus there is a net saving of cost in excavating by the machine of $2\frac{1}{2}d.$ per cubic yard.

This saving has been effected under rather unfavourable circumstances. The summer was wet, and the rain proved injurious to the steep slopes made by the "navvy," by causing slips, thereby often necessitating a day's hand-filling to clear the "navvy" again for work. Moreover, delay was frequently occasioned in the middle of a good working day by the opening of a bridge over a river to let boats through just in front of the cutting; and there was an obstruction from an inclined tramway, which ran down one side of the cutting, and had to be kept clear for through traffic, close to the "navvy." This for fully two months prevented the wagon road being worked on each side of the machine.

Remarks.

Under favourable circumstances the "navvy" may be considered equal to thirty or forty men. In a cutting of clay of small tenacity the steeply excavated sides, and consequent slips in wet weather, might prove a great disadvantage.

The machine possesses an advantage in the dependence to be placed upon its regular work as compared with the frequent losses of time through the strikes and drinking habits of men; and also, in isolated districts, by its saving in the extent of lodging accommodation required for the men. The existence of boulders in the clay to any extent would probably be fatal to the safe working of the machine.

It will have been observed that the capacity of the wagons filled

by machinery has been reckoned at ½ yard more than for those filled by hand; the reason is that the "navvy" possesses the advantage of filling all wagons by an overhead drop, and collars were therefore fixed on to the sides and back of each wagon, so that they held fully 20 per cent. more than they did before.

The improvements to be effected are—

1. The widening of the bucket bale. At present the bucket displaces a portion of the load in the action of drawing in from the face, almost every time; and whereas four bucketfuls are required for each wagon, three would raise just the same quantity if this portion of the load could be preserved to drop through the bucket into the wagon.

2. It would be a great advantage if the jibbing movement could be carried back to about 120° from the centre line, instead of being restricted as it is to about 90°. It sometimes happens that the wagon cannot be got quite at right angles to the jib, in which case the earth falling out of the bucket does not hit the centre of the wagon, and sometimes partly misses the wagon.

3. The catch gear would be better if it could be protected from being smashed against the jib pillar in an occasionally too rapid descent.

4. For cutting gullets, a machine with a taller jib of less radius, with a larger bucket, would be more useful, the present one being best adapted for side cutting, and for excavating large areas.

5. Some regulation of the rapidity of motion in several of the working parts, to give a more steady action, is very desirable.

6. An arrangement for pulling the empty wagon out of the centre road into position for filling, without the use of a horse, which in this operation has to run under the bucket into a rather dangerous position, would be of great advantage.

The Paper is illustrated by a drawing, from which Plate 7 has been engraved.

No. 1,580.—"Results of the Working of Dunbar and Ruston's Steam Navvy." By JAMES BRAND, Assoc. Inst. C.E.

THE Author's attention was first directed to the use of steam power for earthwork cutting in the beginning of 1876, when a steam excavator of American make was introduced into works in his immediate neighbourhood.

The Author's firm at that time had not so much cutting in hand as to warrant the purchase of such an expensive tool; but being anxious to ascertain, by actual experience, the value of this new invention, he commenced inquiries as to prices of different machines. In this way he came to hear of a machine by the above makers, and ultimately ordered one from them to be delivered on rails at their works at Lincoln at the price of £1,150. When delivered, the machine was put to dig out a station yard containing 50,000 cubic yards of stiff, hard, and tough clay, containing boulders weighing from ½ cwt. to 4 tons.

The machine, being only the seventh sold by the makers, was weak in many respects, while the material to be excavated was many degrees more difficult than had ever been attempted by a similar machine. There were therefore at first many breakages, and the various parts of the machine have been one by one replaced, as they gave way, by better and stronger material. After this had been accomplished, the result of the working was as follows:—

There was shifted per day of ten hours an average of about 240 cubic yards of material. This was effected by the employment of the men at the cost as under stated:—

	£.	s.	d.
One engine driver	0	7	0
One brakesman	0	5	0
One fireman	0	3	8
Sixteen navvies	2	18	8
Coals, oil, and waste, 10s.; repairs, 10s.	1	0	0
	4	14	4

Or about 4¾d. per cubic yard.

The cost of operating on the material by hand labour was 1s. 6d. per cubic yard for loading into wagons. The cost of horses and tipping is excluded in both cases.

The Author's firm are now about to employ the same machine, and some others of a similar make, in excavating about 1,000,000 cubic yards of earth at a new dock at Grangemouth, in the Firth of Forth. This will be very soft material, being the ordinary mud deposit found in such estuaries, and for such work the steam navvy is well adapted. But the Author is nevertheless of opinion that a greater saving is effected by applying steam-power to hard material, such as in the station-yard previously mentioned. His experience leads him to believe that, if the machine is made strong enough for the purpose, the saving effected over the cost of hand labour in hard and tough clays is greater than the whole cost of excavating by hand light earths or gravel.

It is, however, to be borne in mind that this remark applies only to dry earth. Wet mud cannot, in the Author's opinion, be excavated with profit by such a machine; and, as the weight of the machine is 31 tons, the material must be such as to afford a good foundation.

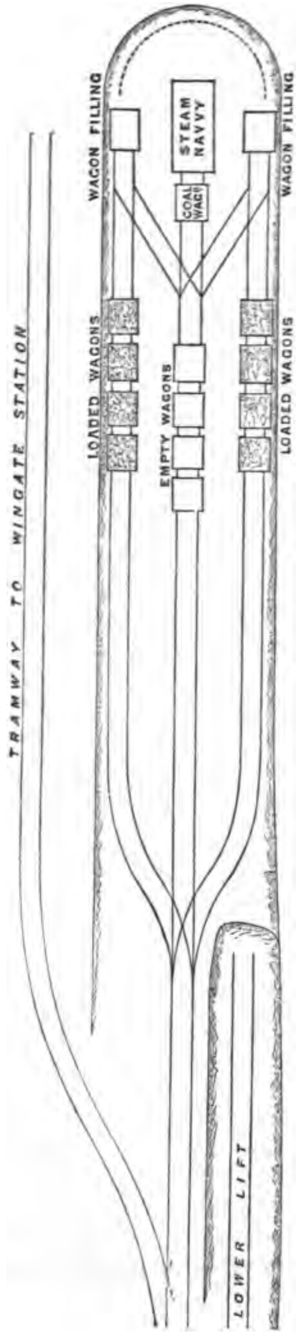
At Grangemouth the Author considers the silt to be too soft; but he is induced to try the steam navvy because there is a stony gravel bed, almost at the bottom of the excavations, extending over the whole area to be operated on, which will bear the weight of the machine. Were it otherwise, the trouble and cost of keeping roads and moving such a heavy engine would render its use impracticable.

No. 1,538.—"Results of the Working of a Steam Excavator on the Castle Eden and Stockton Railway." By Henry Michell Whitley, Assoc. Inst. C.E., F.G.S.

The Castle Eden and Stockton branch of the North-Eastern railway, a line about 14 miles in length, connects the Sunderland and Hartlepool branch near Castle Eden with the Stockton and Darlington railway at South Stockton. In its construction a steam excavator was employed. The Author proposes to give a short account of the machine, and of the amount of work executed by it. The excavator was Dunbar and Ruston's patent, and was built by Messrs. Ruston, Proctor, and Co., of Lincoln. It consists of a strong wrought-iron platform mounted on two pairs of wheels of 10 feet 9 inches gauge, and furnished with six anchor screws by which it is secured during work. From the front of this platform rises a tower of sheet and angle iron, supporting a jib turning on pivots fixed to the platform and tower. Between the frames of the jib a strong wooden beam, furnished at its lower end with a wrought-iron bucket, or scoop, can be raised or lowered by a chain passing over pulleys at the end of the jib and back to a winding drum fixed on the platform, which is driven by a 10 HP. vertical engine. The bucket has a capacity of nearly 1 cubic yard, and is furnished with projecting prongs, the back being closed by a swing door which is allowed to fall open by pulling a rope attached to a spring catch bolt, thus liberating the contents. The jib can be swung round to any desired angle by a chain working around a wheel at its base, whilst the depth to which the scoop enters the face of the gullet, is regulated by a hand-wheel and chain driving a cog-wheel working in a rack on the underside of the beam.

The mode of working is as follows. The bucket being lowered, the engine is set in motion, and draws it up the face of the cutting, the depth to which it enters being regulated by the jib-man at the hand-wheel. Arrived at the surface, the bucket, now full, is swung round over a wagon placed alongside; the catch bolt is disengaged and the contents discharged; the bucket then returns for another sweep, and the third bucketful fills the wagon.

The excavator was set to work in July 1876 in the Embleton cutting, the most considerable on the line, containing 264,000 cubic yards of earthwork. About 100,000 cubic yards of material had



already been excavated in the eighteen months during which the works had been in progress; but owing to the bleak and exposed situation of the cutting, the distance from any town or village, and the consequent necessity of hutting the men on the spot, great difficulty was experienced in getting a sufficient number of labourers to complete the work within the contract time.

The length of the cutting is about $\frac{3}{4}$ mile, the gradients falling continuously towards the south 1 in 178·25 and 1 in 132. The greatest depth was 32 feet, and the average depth throughout the portion in which the "navvy" worked about 25 feet. The material to be excavated was tough and tenacious boulder clay interspersed with pebbles and boulders, the clay increasing in toughness and stoniness with the depth.

The excavator was placed in the centre of a gullet which was run ahead 10 feet above formation level, giving an average depth of face of 15 feet and a width of 44 feet, being the full extent of the reach of the jib.

The arrangement of wagon roads is shown in the accompanying figure. There were three, the centre road for empty wagons, with one on each side for the loaded ones. The excavator worked continuously, filling first a wagon on one side and then on the other, and the loaded wagons were horsed back, made up in trains, and drawn to the bank end by a locomotive.

The results are shown in the Appendix, Table 1, which gives the total quantity of material excavated in a week, the number of days of work,

and the daily average. The men required were an engine-man, fireman, and jib-man, in addition to which from fifteen to twenty men and three boys were employed filling, trimming the sides of the gullet, attending to the roads, and tipping, as well as looking after the locomotive.

The men soon learnt their work, and good results were obtained, the only drawback being that the machine, when first sent, was hardly strong enough to endure the strain brought on it by the extreme toughness of the clay to be excavated. The consequent stoppages from time to time to repair and strengthen various parts that had failed, principally in the tower, hindered progress, but the machines now built being stronger this defect has been remedied.

For the first fortnight a double shift was worked; afterwards a single one of ten hours was adopted, The best week's work (excluding the first fortnight) was that ending the 26th of August, 1876, when 1,964 cubic yards of material were removed, the best day's work being 392 cubic yards on the 25th of the same month. During winter the amount excavated fell off considerably, the best week being that ending the 10th of February, 1877, when 1,627 cubic yards of material were removed, but the usual average was far below this.

The "navvy" completed the gullet on the 10th of March, 1877, the weekly average for the whole time it had been at work being 1,045 cubic yards. The lower portion and the wings left over the slopes were removed, and the cutting was properly trimmed up and put in shape by hand labour, each man excavating on the average between 4 and 5 cubic yards of material per day.

After the completion of this cutting, the excavator was removed to Grindon cutting to drive a similar gullet. This cutting is 30 chains long, on a gradient of 1 in 100, and 20 to 25 feet in depth; the material to be removed was similar to that in Embleton cutting, but not so tough and tenacious, nor did it contain so large a quantity of boulders. The same mode of working was adopted, and the results are shown in Table 2. Owing to the above-mentioned circumstances, and the time being summer, the results are more favourable. The best week's work was in that ending July 7th, when 2,527 cubic yards of material were excavated; the best day's work was 470 cubic yards on the 31st of May, and the weekly average was 1,555 cubic yards.

The Author considers these results to be very satisfactory when the extreme toughness and tenacity of the material excavated are taken into account, as well as the fact that the excavator was one

of the earliest machines constructed by the makers. In those now built greater strength is given to the parts which experience has shown required it, so that the stoppages for repairs are obviated, and consequently still more satisfactory results are obtained. There is no doubt that the adoption of this mode of excavation will greatly expedite the excavation of cuttings, while at the same time it diminishes the cost.

The works referred to are being carried out by Mr. T. E. Harrison, Past-President Inst. C.E., Engineer-in-Chief to the North-Eastern railway, the Author being the Resident Engineer, and Mr. T. Nelson, of York, the contractor.

APPENDIX.

TABLE 1.—RESULTS of WORKING of STEAM NAVVY in EMBLETON CUTTING, CASTLE EDEN and STOCKTON RAILWAY.

Week ending	Total Excavated in Week.	Number of Days Worked.	Daily Average.	Remarks.
1876.	Cubic yds.		Cubic yds.	
July 22 . .	2,255	6	376	Double shift worked.
„ 29 . .	951	4	238	„ „ repairing two days.
Aug. 5 . .	1,246	6	207	Single shift of ten hours.
„ 12 . .	1,510	6	251	
„ 19 . .	1,822	6	303	
„ 26 . .	1,964	6	327	
Sept. 2 . .	1,734	5	347	Stopped by wet one day.
„ 9 . .	1,476	5	295	„ „ „
„ 16 . .	507	3	169	„ for repairs three days.
„ 23 . .	1,592	6	265	
„ 30 . .	..	..	..	Wet week; no work done.
Oct. 7 . .	834	5	167	Stopped by wet one day.
„ 14 . .	559	3	186	
„ 21 . .	1,275	5	255	Stopped for repairs one day.
„ 28 . .	..	..	..	„ „ the week.
Nov. 4 . .	1,016	5	203	„ „ one day.
„ 11 . .	490	2	245	„ four days by snowstorm.
„ 18 . .	362	2	181	„ „ wet.
„ 25 . .	1,326	6	221	
Dec. 2 . .	807	4	202	„ two days by wet.
„ 9 . .	825	5	165	„ one day by wet.
„ 16 . .	319	2	160	„ for repairs four days.
„ 23 . .	..	..	..	Wet week; no work done, and repairing.
„ 30 . .	250	2	125	Stopped four days by wet and holidays.
1877.				
Jan. 6 . .	802	5	160	Stopped one day by wet.
„ 13 . .	1,107	6	184	
„ 20 . .	897	6	149	
„ 27 . .	37	1	37	Stopped five days for repairs.
Feb. 3 . .	394	3	131	„ three „ „
„ 10 . .	1,627	6	271	
„ 17 . .	1,383	6	230	
„ 24 . .	1,269	6	211	
March 3 . .	890	5	178	Stopped one day.
„ 10 . .	877	4	219	„ two days.
Totals . .	32,403	142	..	
Averages .	1,045	..	228	

TABLE 2.—RESULTS of WORKING of STEAM NAVVY in GRINDON CUTTING, CASTLE EDEN and STOCKTON RAILWAY.

Week ending	Total Excavated in Week.	Number of Days Worked.	Daily Average.	Remarks.
1877.	Cubic yds.		Cubic yds.	
April 14 . .	897	5	179	
„ 21 . .	987	5	197	Stopped one day for repairs.
„ 28 . .	701	5	140	„ „ by wet.
May 5 . .	2,230	6	371	
„ 12 . .	1,395	4	349	
„ 19 . .	712	3	228	Stopped three days by wet.
„ 26 . .	1,632	5	326	
June 2 . .	1,882	5	376	Stopped one day for repairs.
„ 9 . .	2,340	6	390	
„ 16 . .	1,870	6	311	
„ 23 . .	2,070	6	345	
„ 30 . .	1,679	5	335	
July 7 . .	2,527	6	421	
„ 14 . .	529	2	264	Stopped four days for repairs.
„ 21 . .	1,672	6	278	
„ 28 . .	2,008	5	401	Stopped one day for repairs.
Aug. 4 . .	2,389	6	398	
„ 11 . .	1,945	6	324	
„ 18 . .	1,675	6	279	
„ 25 . .	1,077	4	269	Stopped two days by wet.
Sept. 1 . .	455	2	227	
Totals . .	32,672	104	..	
Averages .	1,555	..	305	

No. 1,538A.—"Results of the Working of a Steam Navvy at the West Hartlepool Docks." By Charles Augustus Harrison, M. Inst. C.E.

The machine employed at these docks was one of Messrs. Ruston and Proctor's, and has been materially and successfully strengthened at all the points which proved weak in former machines of the same kind. It has never been stopped for repairs. Blank days are to be accounted for by the fact that the excavation was nearly completed, and consequently the engine had to be moved from one place to another. The earth also fell, and by blocking up the wagon roads prevented good results on several days. The wagons employed were 6 feet 9 inches long, 6 feet 9 inches wide, and 2 feet deep, having a capacity therefore of 3 cubic yards. The following table shows the results:—

Hartlepool New Docks. Wagons filled by Steam Navvy.

Date.	Number of Wagons.	Date.	Number of Wagons.	Date.	Number of Wagons.
1877		1877		1878	
November 15	50	December 20	170	January 22	183
„ 16	80	„ 21	138	„ 23	171
„ 17	52	„ 22	37	„ 24	183
„ 19	123	„ 24	18	„ 25	178
„ 20	54	„ 25	..	„ 26	117
„ 21	110	„ 26	33	„ 28	60
„ 22	..	„ 27	149	„ 29	167
„ 23	25	„ 28	170	„ 30	162
„ 24	36	„ 29	93	„ 31	143
„ 26	131	„ 31	111	February 1	161
„ 27	160			„ 2	60
„ 28	165	1878		„ 4	28
„ 29	96	January 1	15	„ 5	191
„ 30	18	„ 2	104	„ 6	240
December 1	..	„ 3	110	„ 7	220
„ 3	77	„ 4	..	„ 8	216
„ 4	156	„ 5	..	„ 9	62
„ 5	102	„ 7	..	„ 11	202
„ 6	53	„ 8	83	„ 12	161
„ 7	15	„ 9	111	„ 13	66
„ 8	61	„ 10	90	„ 14	83
„ 10	149	„ 11	140	„ 15	121
„ 11	153	„ 12	61	„ 16	80
„ 12	120	„ 14	124	„ 18	72
„ 13	110	„ 15	113		
„ 14	28	„ 16	152	Working days, 74.	8,353
„ 15	..	„ 17	170		
„ 17	..	„ 18	210		
„ 18	117	„ 19	156	Average, 112·8 wagons per day.	
„ 19	158	„ 21	169		

No. 1,580A.—"Remarks on Steam-excavating Apparatus, and its Results in Use." By Messrs. Ruston, Proctor, and Co.

Although Messrs. Dunbar and Ruston's steam navvy has been practically introduced but little more than two years, Messrs. Ruston, Proctor, and Co., the sole manufacturers, have turned out upwards of thirty machines, the majority of which are in operation in England, with a few in France. Since the conditions under which these work differ more or less in almost each case, every opportunity has been presented to observe the practical working of the machine. It has consequently been continually improved and strengthened as various modifications were suggested or weak points presented themselves.

On account of the varying conditions, as might reasonably be expected, there is considerable difference in the opinions expressed by the various contractors who use them. While some would prefer a machine with a "taller jib of less radius," others think the range of the bucket should be extended as much as possible. Not less diversity is there in the practical working of the machine. The first one turned out, which was considerably lighter than any of the succeeding ones, worked for nearly six months in very stiff clay, without requiring any repairs worth mentioning, whilst the next machine, at work within a few miles, in perhaps rather heavier stuff, required in a short time the addition of stays, &c.

There is a similar variation in the amount of work obtained from the steam navvy. There has been as large an average as one hundred and fifty to one hundred and sixty wagons turned out day after day, equivalent to more than 500 cubic yards of material. Much depends upon the peculiar conditions under which each machine works, and also much upon the handiness and skill of the men in charge. A few minutes' delay in bringing up or removing the wagons at intervals throughout the day mounts up seriously at the end of the week. In the same way unnecessary time is sometimes occupied in moving forward the machine. With one machine breakdowns and stoppages are of rare occurrence; whilst in another of exactly the same proportions and material, doing similar work, wear and tear seem unaccountably great, coupled with frequent little hitches.

Regarding the manufacture of the steam navvy, there is hardly any portion of it, even to seemingly insignificant details, that, since the first introduction, has not been considerably modified,

either in design or proportion, to bring it into accord with the claims of practical experience. Among these alterations may be mentioned:—1st. Improvement of the hinge and catch gear of the bucket lid, making it quite automatic in closing and obviating the need of manual help; the catch lever is also made with a folding joint, so that in the event of any unlucky slip on the part of the driver no damage is done to it. 2nd. The bucket bale is made higher, and is much altered in construction, allowing more room for the "dirt" to pile up on the bucket. 3rd. The engines are all provided with efficient governors to check the speed in case of any momentary inattention. 4th. The jib has a larger angular range to allow more latitude in placing the wagon tracks, the distance of which being once fixed for any particular cutting it must be evident that there will be one angular position of the jib in which the bucket will best empty itself into the wagon, and any further back movement of the jib, although giving greater range to the position of the wagon on the track, would also bring the bucket too near to the machine to suit the centres of the wagon ways.

Among improvements also in the actual construction and arrangement are a thorough and efficient system of stiffening the frame, tower, and jib, a simplified propelling gear, and the tapered main drum, for varying the speed of the bucket and proportioning the power required for working the same to the varying resistance. Many other details might be enumerated, but these will be sufficient to show that every effort is made to render the steam navvy as successful as possible, both as regards durability and practical efficiency.

The cost per cubic yard excavated, or what may be termed the "financial duty" of the machine (the relative saving over hand labour), varies in almost every case, but that there is a saving, and a considerable saving too, is confidently affirmed. A brief examination of the tables accompanying the previous Papers will be sufficient to prove this.

TABLE A.—*Paper No.* 1,566.

	Cubic yards.	Total cubic yards.
Daily average	190	24,000.
	d.	Total cost.
Cost per cubic yard.	8¼	£874.
" " by hand labour . .	10¾	£1,075.
Net saving per yard	2½	

Total saving £201 in 126 working days.

REMARKS.—Rather unfavourable circumstances. The summer was wet, delay was often occasioned, &c.

From Table C, "Combined Daily Average," it will be observed that the above quantity of 190 yards per day is much less than in other cases, involving therefore much greater cost per yard.

TABLE B.—*Paper No.* 1,580.

	Cubic yards.	Total cubic yards.
Daily average	240	50,000.
	s. d.	Total cost.
Cost per cubic yard	0 4¾	£990.
" " allowing for depreciation, interest, &c. .	0 5½	£1,146.
" " by hand labour . .	1 6	£3,750.
Net saving per yard	1 0½	

Total saving £2,604 in 208 working days.

REMARKS.—Material to be excavated was many degrees more difficult than had ever been attempted by a similar machine.

TABLE C.—*Combined Daily Average.*

	Cubic yards.	Number of working days.	Total cubic yards.
No. 1. Paper No. 1,566. Daily average .	190	126	24,000.
" 2. " " 1,580	240	208	50,000.
" 3. " " 1,538. First cutting .	228	142	32,403.
" 4. " " 1,538. Second cutting .	305	104	32,672.
" 5. " " 1,538A.	338	74	25,059.
Average cubic yards per day .	260		
NOTE.—Taking Nos. 2, 3, 4, and 5, average per day	278		

It is to be regretted that particulars of cost are not given with Nos. 3, 4, and 5 (Table C), so that they might be tabulated in the same manner as Nos. 1 and 2 are in Tables A and B. In Table B the machine, working in what is described as exceptionally difficult stuff, pays for itself more than twice over in two hundred and eight working days. This agrees with the report frequently given of the steam navvy, viz., "that the machine pays for itself in six months." Messrs. Ruston, Proctor, and Co. have even been informed that "the stiffest clay has been excavated and filled into wagons with a working expense of 2*d*. per cubic yard."

Generally the harder and tougher the stuff is the greater is the saving over hand labour. To suit the different materials the same-sized machine has been supplied with buckets of from 1 yard to nearly 2 yards capacity, the most useful size being the 1 yard.

The working face may be as much as 20 to 25 feet deep, the deeper the better, other things being equal, as then less propor-

tionate time is lost in moving forward the machine. In this case also the kind of material fixes the most economical depth to work at. Cuttings in which there are two wagon tracks will give a much better result than those in which there is only room for one track, there being less delay in bringing up the wagons, and a less average distance swung round by the jib. The last objection applies also to machines working a longitudinal face, when more time per day is occupied in moving forward, owing to the jib having but two-thirds the range of cut that it has when working in a gullet, excavating one-third less material between each forward movement, and necessitating a forward movement more frequently, in the proportion of 3 to 2, an important item in the long run. It is almost superfluous to add that the greater the content of the excavation the more profitable is the return, less time and money being expended proportionately in fixing and getting the machine to work.

In conclusion the advantages of the steam navvy may be summed up as follows. It will excavate and deliver into wagons 500 to 600 cubic yards of stuff per day. It is suitable for any kind of material from sand and gravel to the toughest clays. The net saving amounts to from 3*d.* to 1*s.* and upwards per cubic yard excavated. It will turn out work requiring fifty to sixty navvies to accomplish by hand. It can readily be handled by two men and a boy. It effects a great saving in time, especially when that lost through strikes is taken into account. Finally, it can quickly be set to work in situations where it would be difficult to get the requisite hand labour, and still more so to keep together a large body of men.

MEMOIRS OF DECEASED MEMBERS.

MR. WILLIAM WELHAM CLARKE was educated at the College for Civil Engineers at Putney, and obtained the College diploma. Between the years 1848 and 1855 he was in the employment of the Messrs. Lucas, contractors, as agent for conducting works, and was engaged on the City of Norwich Waterworks, the Great Yarmouth Waterworks, the Lowestoft Waterworks, the filters at Royal Mills, Esher, the Lowestoft drainage, and numerous building works, chiefly in the Eastern counties. In the year 1855 he entered the service of the Hon. East India Company as a special Engineer, and in the following year was graded in the Public Works Department as Executive Engineer, 4th class, attaining the 1st class in 1865. In India he had charge of the construction of barracks and public buildings at Agra, of the rebuilding a church at Muttra, of the construction of suspension bridges in Kumaon and Gurhwal in the Himalayas, of the Rohilcund State Railway Survey, of the Kumaon Ironworks, of the Bundelcund Irrigation Works, of the Rohilcund Imperial road, and of the Gwalior roads. He was in England during part of 1867 and 1868, and after returning to India had charge of the Benares division of roads till 1872, when he was transferred to Rajpootana for the purpose of designing irrigation works in Mhairwara. Subsequently, in December of that year, he was posted to the Western Rajpootana railway survey, of which during three months in 1875 he officiated as Engineer in Chief. Early in January 1876 he obtained twelve months' leave of absence on medical certificate, and on the 27th of July, 1877, died of abscess in the bronchial tubes. He twice received the commendation of the Government of India for his services.

Mr. Clarke was elected a Member of the Institution on the 7th of April, 1868.

MR. WILLIAM THOMAS DOYNE, the second son of the Rev. J. Doyne, Perpetual Curate of Old Leighlin, in the county of Carlow, Ireland, was born in April, 1823. He commenced his education as an engineer at Durham University in the year 1839, but only remained there about eight months. In the summer of

1840 he was articled to the late Mr. Edward Dixon, M. Inst. C.E., who at that time was an assistant engineer under the late Mr. Joseph Locke, M.P., Past-President Inst. C.E., in the construction of the London and South-Western railway, with the branch line from Bishopstoke to Gosport. Before his pupilage was completed, Mr. Dixon, having formed a high opinion of his abilities, recommended him as an assistant engineer on a line then being made from Hamburg to Burgedorf, a town about ten miles from Hamburg. He remained there till the opening of the line in 1843, and was next employed on the Great Southern and Western railway of Ireland, where the present main lines were only then being commenced, first under Sir John Macneill, M. Inst. C.E., and afterwards under Mr. Hemans, M. Inst. C.E. His next employment was under his old master, Mr. Dixon, who was joint engineer with Mr. Robert Dockray, in laying out many lines for the London and North-Western Railway Company; and in 1847 he was appointed by them resident engineer of the Rugby and Leamington railway, of which he had almost the sole management till it was opened at the commencement of 1850. A description of a wrought-iron lattice bridge, constructed over this line, was communicated by him to the Institution,[1] for which he was awarded a council premium of books in 1850; and in the following year, in conjunction with Mr. W. B. Blood, he submitted a Paper on "An Investigation of the Strains upon the Diagonals of Lattice Beams, with the resulting Formulæ,"[2] which met with a similar acknowledgment. About this time he devoted a good deal of attention to the study of mineralogy, and in 1851 made the acquaintance of Mr. Richard Fothergill, of the Aberdare Iron Works, and of Mr. Thomas Brown, of the Ebbw Vale Iron Company. He was employed by these gentlemen, first to investigate the value of reported iron mines in various parts of England and Wales, and to negotiate with the owners for the sale of the ore; and then, as Engineer of the Aberdare Iron Works, where he rearranged a large portion of the works, altering furnaces, putting up new iron roofs, &c. In this capacity he showed so much talent as an organiser, an engineer, and a geologist, that his services were retained by the Ebbw Vale Company, and he settled in Newport. There now seemed every promise of his rising to fortune and professional eminence. Unfortunately, disputes arose with his employers, involving law-suits, in which, however, he was suc-

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. ix., p. 353.
[2] *Ibid.*, vol. xi., p. 1.

cessful; but they led to the connection being terminated, and he returned to London to seek employment. After a time, when the Crimean War broke out, he was sent out to Balaclava in charge of the Army Works Corps, consisting of about two thousand four hundred navvies and artificers, to assist the military authorities in making roads. With this staff, aided by four civil engineers under him, he carried out various works, the principal one being a road from Balaclava to the port near Sebastopol, about nine miles in length. On returning to England, at the termination of the war in 1856, he entered into partnership with the late Mr. Robert Garrett, M. Inst. C.E., who had been second in command of the Army Works Corps. Amongst other undertakings engaged in by them was the survey of a proposed railway between Cawnpore and Lucknow. This work Mr. Garrett had just completed when the Indian Mutiny broke out, and he perished in assisting to defend Cawnpore. In October 1857 Mr. Doyne was selected to fill the position of Chief Resident Engineer in Ceylon, in connection with the survey and construction of the Ceylon railway, proposed to be made from Colombo to Kandy. Under Mr. Doyne's personal supervision surveys were completed of this line, notwithstanding serious difficulties of country and climate; but in 1859, differences having arisen with the Consulting Engineer, Mr. Doyne was recalled, and eventually the Company was dissolved, and the construction of the railway was undertaken and completed by the Colonial Government. Mr. Doyne's health having become much impaired from overwork, anxiety, and climatic influences while in Ceylon, he, with a view to re-establish his constitution, engaged with the Dun Mountain Copper Mining Company, whose works were situated near the city of Nelson, in New Zealand, to select the best line of route for, and superintend the survey of, a line of railway from the port of Nelson to the Company's works at the Dun Mountain. Assisted by Mr. A. FitzGibbon, M. Inst. C.E., who had acted as second to Mr. Doyne on the Ceylon railway, the survey for the Dun Mountain railway, the first in New Zealand, was completed. Mr. Doyne left that colony in 1861 to superintend the surveys for, and eventually the construction of, the Launceston and Deloraine railway in Tasmania, in which he was associated with Mr. E. Digges La Touche. At the same time he was employed by the New Zealand Government in the repairs of harbours, and in altering the course of rivers, and made two reports in June 1864, and November 1865, on the plains and rivers of Canterbury. Meanwhile he had paid a short visit to England, about the end of the year 1862, when he was utterly prostrated by

illness. In 1866 he established himself in general practice in Melbourne, Victoria, and in that year was consulted by the Queensland Government in connection with railways for the colony. He was also engaged as chief engineer for the Launceston and Western railway, in Tasmania, in partnership with Messrs. Major and Willett, and directed the preliminary survey of the main line of railway in the same colony, besides constructing a bridge of 190 feet span over the South Esk river, near Launceston. In 1869 he was appointed Consulting Engineer to the Government of Western Australia, which colony he visited for a short time to report on public works. In fact, during his sojourn in Melbourne, he enjoyed as much practice as his shattered health admitted of his undertaking; being occasionally consulted by the Governments of Queensland, of South Australia, and of Western Australia, besides doing other work. He died at Melbourne on the 29th of September 1877. Mr. Doyne was a clever and painstaking engineer, a good mathematician, geologist, and analytical chemist, and was unusually well read and informed on most subjects. He was of a sanguine temperament, brilliant, cheerful, and of great conversational powers. Understanding thoroughly the duties of his profession, and having capacity to undertake them, he never shrank from responsibility, more than his due share of which he was always ready to take. This, combined with his social qualities, caused him to be much endeared by his subordinates. In those undertakings in which he was associated with others, he insisted on responsibility being so apportioned that in the event of any failure in the conduct of affairs "the saddle might at once be put on the right horse," as he used to say.

Mr. Doyne was elected an Associate of the Institution of Civil Engineers on the 6th of March 1849, and was transferred to the class of Members on the 9th of November, 1852.

MR. ROBERT JEFFREY (Bey) was born on the 9th of February, 1813, at Shilbottle, near Alnwick, Northumberland. He was never actually apprenticed, but in the year 1834, when about twenty-one years of age, he entered the service of Messrs. Robert Stephenson and Co., and at their Engine Works, South Street, Newcastle-on-Tyne, then under the able direction of the late Mr. Hutchinson, he soon became an expert workman.

In December 1839, he was selected by the late Mr. Robert Stephenson, M.P., Past-President Inst. C.E., to act as foreman

over a portion of the works at La Ciotat, near Marseilles, which Messrs. Louis Benet and Co. intended to devote to the construction of locomotive engines. When the first three engines were finished, he took them to Naples, where he erected them upon the line, and for a time superintended the locomotive service between Naples and Torre del Greco. After completing his contract time of service at La Ciotat, he returned to Newcastle. In November 1841, he became temporary locomotive superintendent on the Leeds and Selby railway. In April 1842, he took charge for Messrs. Robert Stephenson and Co. of the two first long boiler engines constructed by the firm for the Düsseldorf and Elberfeld railway. On arrival, he found that line almost at a standstill for want of motive power, but he soon improved the rolling stock, and with the aid of the new engines placed the traffic on a sound footing. The Directors demonstrated their satisfaction by a substantial pecuniary recompense. In December 1842, he was sent by Messrs. Robert Stephenson and Co. to Naples in charge of six locomotive engines for the service between that city and Caserta; and on this line, in spite of severe opposition from rival engineers, both English and American, he was successful in demonstrating the good quality of the engines entrusted to him. In June 1843, he was appointed to the position of Locomotive Superintendent on the Leghorn and Florence railway, where he had almost everything in the way of machinery to create, and by incessant and intelligent attention to his duties, and indomitable courage, he overcame all the difficulties of the position with credit to himself and advantage to the railway company. In March 1857, he returned to Newcastle, with further marks of the satisfaction of his employers.

For some time H.H. Said Pasha, then Viceroy of Egypt, had been discontented with the management of the locomotive department of the Egyptian Government railway; whilst the complaints of the British Government and of the Peninsular and Oriental Steam Navigation Company were incessant as to the defective service on the railway. His Highness, therefore, through the late Mr. Hugh Thurburn—then of Alexandria—applied to the Council of the Institution of Civil Engineers to select a competent person for the post of superintendent of the locomotive engine and carriage department. Sixty-five applications were received, and after careful investigation of the qualifications and experience of all the candidates Mr. Robert Jeffrey was selected in November 1857. He immediately started for Egypt and commenced the great work of his career. He found the whole establishment at

Boulac, for the repairs of locomotive engines and carriages, an Augæan stable of the worst description; but, nothing daunted, he set to work "with a will," and in spite of passive and active opposition he soon made his mark. Mr. Hugh Thurburn never failed, on occasions of difficulty, to place any correct statement before H.H. Said Pasha, who appreciated the sturdy qualities of Robert Jeffrey, and accorded to him the utmost confidence. At first the labour was excessive. The locomotive and carriage-shops at Boulac were but scantily provided with useful tools, and the distribution of the establishment was entirely without system; whilst the engines, carriages, and wagons were of many different types, as the Viceroy never hesitated to give an order to supply something for the unfortunate railway to any one who was merely presented to His Highness. Patient labour, however, eventually prevailed, and Jeffrey persuaded the authorities to adopt certain types of engines and rolling stock, and to adhere to them. In this vital principle, however, he was only partially successful. The next great difficulty was the conduct of the European drivers of the engines, who were of all nationalities, and generally inefficient. A staff of Englishmen was selected for the service, and sent over, upon good pay and under stringent rules; but the climate and the love of strong drink overcame them. Then, after trying everything in favour of his countrymen, Jeffrey proposed to H.H. the Viceroy to attempt to train native Arab drivers for the service. The suggestion was adopted, and it was agreed that Jeffrey should receive a premium of £100 sterling for every Arab driver he could train to pass the examination of a competent committee. The experiment was successful, and there are now only a few English drivers in the service.

At the time of the International Exhibition of 1862, Mr. Jeffrey accompanied H.H. Said Pacha, the Viceroy, to Europe, and selected many articles required for the Egyptian railway service. Soon afterwards the Viceroy died; but the merits of Mr. Jeffrey were too well established to permit him to be disturbed. Moreover, he had impressed H.E. Nubar Pacha, who then held the position now so efficiently filled by General Marriott, C.S.I., and who had long known him, with the valuable character of the services he could render; so that when an enlightened and liberal superior like H.E. Nubar Pacha was appointed Minister of Public Works, Mr. Jeffrey felt satisfied that every useful suggestion would be laid before H.H. Ismael Pacha, the present Khedive. Careful private reports upon the line and works were made by an engineer

who enjoyed the confidence of H.H. the Khedive. Improvements were effected in every branch of the service; the all-essential point of unity of type of engines and rolling stock was, as much as possible, enforced, and the railway assumed almost an European aspect. The energy and physical powers of Jeffrey were severely taxed, but he was equal to the occasion; and he had the satisfaction of finding that his services were recognised by increased remuneration, and in 1864 he received from H.H. the Viceroy the title of Bey.

Once, when the line was so blocked by cotton bales and other merchandise that an entire stoppage of the traffic was imminent, he was appealed to by H.E. Nubar Pacha. His response was to commence systematically with powerful gangs, to remain day and night upon the scene of action for upwards of a week, and not to leave until every bale was cleared away.

When an outbreak of cholera occurred, and the majority of the employés, workmen, and drivers abandoned the railway and the works, Jeffrey with his secretary, Mr. C. G. Harison, remained true to their trust. They rallied the few English drivers who could be found, reassured them by example, kept them up to their work, and maintained the passenger service of the line throughout that dreadful visitation.

Time and hard work in such a climate had, however, made certain ravages upon his naturally strong constitution, and when, in 1866, he resigned his appointment and returned to England, he was comparatively only the shadow of his former self. He, to a certain degree, regained his health and was enabled to travel frequently on the Continent, but the seeds of disease could not be got rid of, and at length, feeling more than usually unwell, he went to Manor Farm, Ilford, Essex, for change of air, and within a few weeks died peacefully on the 21st of December, 1877, in the arms of his only remaining son, Thomas Jeffrey, who had recently returned from Canada at the invitation of his father—his two daughters being in South America.

Mr. Robert Jeffrey was elected a Member of the Institution on the 3rd of December, 1861. He was a well-developed specimen of the good old-fashioned type of the British workman; strong physically and mentally, and determined to do his duty under all and any circumstances.

MR. FREDERICK WILLIAM KITSON was born at Leeds on the 29th of June, 1829. He was the eldest son of Mr. James Kitson, J.P., of Elmete Hall, Leeds, the founder of the firm of Kitson and Company, of the Airedale Foundry, where the subject of this memoir first qualified himself as an engineer, and where he became the head of the drawing office and principal designer of locomotive engines. In the year 1854 he joined his father and brother, Mr. James Kitson, junior, in the establishment of the Monk Bridge Iron and Steel Works, which concern in busy times employs upwards of seven hundred hands. These works, which are devoted chiefly to the manufacture of railway material, such as boiler-plates, tires, and axles, are fitted up with all the most approved modern appliances, and in their construction the particular talent of Mr. F. W. Kitson found ample room for its exercise. He was a patentee of several inventions which have had successful practical application. The solid weldless iron tires, a hydraulic friction clutch for rolling mills, and an improvement in the manufacture of tires for railway wheels, are amongst these.

Mr. F. W. Kitson was elected a Member of the Institution of Civil Engineers on the 12th of January, 1869. He was a Vice-President of the Iron and Steel Institute, an association in the promotion of which he took an active part, and always manifested a warm interest in its subsequent success. When the Institute visited Leeds in 1876, he was chairman of the reception committee. He was also a Member of the Council of the Institution of Mechanical Engineers.

The infirm state of his health latterly prevented his taking any active part in public affairs, but in business circles he was esteemed for eminent ability as a practical engineer, while, in social life, he was most genial, open-hearted, and generous. He died on the 25th of November, 1877.

MR. BRYCE MCMASTER, the son of Brigadier-General McMaster, was born in the year 1832. He became a pupil of Mr. T. H. Bertram in 1848, and was employed on railway works for the late Mr. I. K. Brunel, V.-P. Inst. C.E., in 1852 and 1853. In August of the latter year he entered the service of the Madras Railway Company as an Assistant Engineer, and carried out with great credit, and very cheaply, some extensive cuttings and earthworks, as well as two large stone bridges, on the third district of the

first extension, a length of 20 miles. In August 1856, he was promoted to the grade of Resident Engineer, and was placed in charge of the permanent way of the first division of the line which had been opened in July. In that position he remained till January 1862, when he left the service of the Company. He then became a member of the staff of Messrs. Brassey and Wythes, and was engaged immediately under Mr. J. A. Longridge, M. Inst. C.E., on the Mauritius railways for about four years. On his return to England, he submitted competing designs in the spring of 1866 for the new Waverley Station in Edinburgh, for which he was awarded a premium, as successfully dealing with a difficult problem. He afterwards assisted in connection with the ordering of materials for the Delhi railway, on behalf of the contractors; and from February 1872 to October 1873 was employed by the Public Works Construction Company as Sub-Agent, and subsequently as Agent, on the East Argentine railway. At the latter date he was obliged to return to England on account of ill-health. Finally, in March 1877, Mr. McMaster again entered the service of the Madras Railway Company as an Assistant Engineer, but he had not been long in India before he died, on the 7th of October, 1877, at the age of forty-four years.

Mr. McMaster was elected as Associate of the Institution of Civil Engineers on the 7th of April 1857, and was transferred to the class of Members on the 18th of February 1862. In 1859 a Paper of his, descriptive of the "Permanent Way of the Madras Railway,"[1] led to an interesting discussion on the comparative merits of wood and iron sleepers for Indian railways. Four years later he presented a further Paper, "On the Woods used for Sleepers on the Madras Railway."[2] Both these communications may be taken as evidence that his mind was actively occupied with the details of his charge, while in carrying out the works entrusted to him he proved himself to be intelligent, careful, and persevering.

MR. WILLIAM PRICE STRUVÉ, the second son of the late Mr. George Struvé, M.D., of Jersey, was born in that island in the year 1809. He was educated at the private school of Mr. Le Gros, where he soon gave promise of superior mathematical talents.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xviii., p. 417.
[2] *Ibid.*, vol. xxii., p. 241.

At the age of fifteen he was articled to his brother-in-law, the late Mr. H. H. Price, M. Inst. C.E., who, having a large practice, was able to give his pupil a varied instruction in mechanical as well as civil engineering. Mr. Struvé appears to have had a preference for that branch of the profession which more specially relates to the working of coal and iron; and as far back as the year 1834 he was Managing Partner of the Millbrook Iron Works. On establishing himself in Swansea, he soon acquired an extensive practice in connection with collieries, his practical as well as theoretical attainments being fully recognised, and his lively interest in everything connected with coal or iron never abated. His zeal for the interests of the Geological Survey of Great Britain was very great, and although he had plenty of other professional work, he nevertheless found time to render useful aid to Mr. (now Sir E.) Logan, as shown in a section which bears his name. His hearty way of going to work carried others along with him, and often turned what at first sight appeared full of drudgery into a pleasant and interesting labour. One of the most practical results from this survey was his Paper on the "Great Anticlinal Line of the Mineral Basin of South Wales," read before the British Association for the Advancement of Science at Swansea in the year 1848, and in which were foreshadowed the immense resources of the Rhondda coalfield, now producing perhaps the finest steam coal at present worked. In the year 1860 he accepted the post of Manager of the Cwm Avon Works under the Governor and Company of Copper Miners in England, a position he held for about ten years, but he had previously for a long time served the Company, in connection with their extensive collieries, as consulting Mining Engineer. Here was erected one of the first of his mine ventilators, which have since fully realised his expectations of their utility; although it would perhaps have been more profitable to Mr. Struvé could he have overcome an innate dislike to push his inventions before the public. Another invention, which is highly appreciated by those who have used it, is his safety lamp. As a surveyor's lamp there is none to beat it, and if it were more widely known, it would be a boon to those who are obliged to do delicate work with insufficient light in fiery collieries. Whilst at Cwm Avon, his attention was naturally much turned to the manufacture of iron—the result being the production of a homogeneous iron with which he proposed to top rails. Amidst the revolution which has taken place in the manufacture of railway iron by the introduction of steel, this process has been somewhat lost sight of; but practical experiments fully demon-

strated the strength and economy of the material. His attempt to nullify the injurious effects of copper smoke, by converting it into sulphuric acid, gave promise of commercial success, but the resignation of his post in the year 1870 hindered its proper development, much to the disappointment of many friends. After leaving Cwm Avon, he gradually withdrew from the profession, and having settled at Neath, he took a short rest after an energetic career, passing away on the 10th of April, 1878.

If there be one thing by which Mr. Struvé ought to be remembered, it is that he was the first to introduce mechanical ventilation into Welsh collieries. For a Paper on "The Ventilation of Collieries, &c.," read before the Institution on the 19th of November, 1850, he received a Telford Medal.[1] His life was one of work, not so much for himself as for others, and it is not only among his own relations that his loss as a friend is felt. This is not the place to descant on his private virtues; but as illustrative of his kindly feeling, it may be mentioned that, on one occasion when it was suggested that his views had been criticised with unnecessary warmth, during a discussion at the Institution, Mr. Struvé replied, to this effect, "No, when you have lived a little longer, you will find that life is something like the manufacture of a rail: we come into the world like the raw iron; get puddled and hammered and squeezed and rolled, but at last the finished rail is produced. The more thoroughly the process is carried out, the better the finished rail." He thoroughly understood workmen, and amongst colliers was reckoned to be a collier; added to which his intimate knowledge of the South Wales coalfield made his opinion valuable. He was examined on more than one occasion before Committees of the Houses of Parliament on matters connected with the working of coal, and at one time of his life had a good deal of employment as an arbitrator in such matters. Probably few men were more trusted, and that trust was never misplaced.

Mr. Struvé was elected a Member of the Institution of the Civil Engineers on the 6th of March, 1849.

MR. CHARLES TARRANT, the son of Mr. Charles Tarrant, Engineer to the Grand Canal Company, was born in Dublin in 1815. He was educated by a connection named Crawford, who

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. x., p. 22.

resided in the neighbourhood of Dublin, and was apprenticed to his father, being engaged on the Grand Canal and on private works. He became Assistant Engineer to the Grand Canal Company under his father, and afterwards went to Scotland in connection with Mr. Henry, who was employed in the construction of the Edinburgh and Glasgow railway. He returned to Ireland on the completion of that work, and became Assistant Engineer to the Waterford and Kilkenny railway, under the late Captain Moorsom, M. Inst. C.E. On the completion of that line, he accepted an engagement on the Susquehanna and Reading railway, in America, where he, during some years, pushed on the works vigorously, employing vast numbers of both German and Irish navvies; but the climate did not agree with his family, and he abandoned the work and returned to Ireland. Having passed a competitive examination for the office of County Surveyor, he was appointed by the Lord Lieutenant of Ireland to Monaghan, and soon after exchanged to Waterford, which he held to the time of his death. He was largely employed in the district in architectural as well as in drainage works; the amalgamated prison of the county and city of Waterford being one of his principal public buildings. In conjunction with Mr. Wellington Purdon, M. Inst. C.E., he was appointed Engineer to the Waterford, Dungarvan, and Lismore railway, now approaching completion, under the Companies Acts of 1872 and 1873. He died suddenly on Tuesday, the 31st of July, 1877, from heart disease of long standing. He was a thoroughly upright, single-minded man, and his county works, roads, &c., are admittedly amongst the best in Ireland. A few months before his death, he was appointed, by the Lord Lieutenant, joint Commissioner, with Mr. W. Forsyth, of the Board of Works, and the County Surveyor of Cork, to report on Youghal bridge, connecting the counties of Cork and Waterford; and plans prepared by him for the erection of a permanent stone and iron structure, to replace the present decayed wooden bridge, were unanimously approved by the grand juries of Cork and Waterford.

Mr. Tarrant was elected a Member of the Institution of Civil Engineers on the 5th of December, 1865.

MR. JOHN RUSSELL FREEMAN, the fourth and last surviving son of Mr. William Freeman, of Millbank, was born in Westminster on the 17th of March, 1826. He was brought up as a stone

merchant, and was for some years, and until the time of his decease, in partnership with his father. He was elected an Associate of the Institution on the 7th of February, 1871, and he died, after a short illness, on the 20th of January, 1878.

MR. RICHARD HALL was born in 1806 at Cirencester in Gloucestershire, and succeeded his father and grandfather in the practice of a land agent and surveyor at the early age of twenty-one. He was soon largely engaged in surveys and valuations in connection with the Tithe Commutation and Inclosure Acts, and the Poor and County Rate. During the growth, and on the establishment, of the railway system he was much concerned, principally on behalf of the companies, but frequently also on that of owners, in the settlement of land purchases and sales, and in this way became associated with the late Mr. I. K. Brunel, Vice-President Inst. C.E., who continued a warm friend through life. Owing to this connection he was employed in the purchase of a large portion of the land required for the present Great Western railway. Among the labours of his earlier life he rendered much assistance in establishing the Agricultural College at Cirencester. About the year 1850 he removed to London, where his general practice, particularly in parliamentary work and in the capacity of arbitrator or umpire, rapidly increased; and there are few to whom it has more frequently fallen to have the settlement of matters on both sides left entirely in their hands. He was on the list of arbitrators to the Board of Trade, and was consulted by the Government with reference to the management of portions of the Royal Forests, and with respect to the rating of the Government property in those parishes where it occupied a large area, but contributed nothing in aid of the poor rate; and on his advice the basis was settled for arriving at a rateable value in all the important establishments, including those of Portsmouth, Plymouth, and Woolwich. Mr. Hall had, for some years before his death, retired from the more arduous duties of his profession; but he took great interest in the Institution of Surveyors, established through the exertions of Mr. John Clutton, Assoc. Inst. C.E., and succeeded that gentleman as President, holding the office for two years, during which his inaugural addresses related to the Irish Land Act and the operation of the Inclosure Acts. He was the principal adviser of several noblemen and large landowners, and held at the time of his death, which occurred on the 22nd of February, 1878, many

prominent public offices. He was also a deputy lieutenant for the County of Brecknock, and a magistrate for Glamorganshire.

Mr. Hall was elected an Associate of the Institution of Civil Engineers on the 5th of January, 1861.

Mr. JOHN LEAN, the fifth son of Captain Francis Harris Lean, was born at Crowan in Cornwall, on the 22nd of March, 1818. At the age of fourteen he was engaged to a mechanical engineer, and assisted in the erection of a Cornish engine, an occupation followed for several years, during which he made himself acquainted with the general method of conducting Cornish mines. In 1842 he received an appointment on the Bristol and Gloucester railway under the late Mr. I. K. Brunel, V.-P. Inst. C.E., as Inspector of Works, and had charge of the Staple Hill tunnel. Removing to the South Devon railway in 1844, he was placed in charge of the sea wall on that line under Mr. J. T. Harrison, M. Inst. C.E. In 1847 he was advanced to the position of Assistant Engineer under Mr. W. G. Owen, M. Inst. C.E., at Newport, on the South Wales railway. He had now become acquainted with the general nature of railway works, and displayed considerable ability and perseverance in carrying out their construction. About the year 1858 he was appointed Resident Engineer of the Vale of Neath railway, and in 1862 was Chief Engineer for the construction of the Swansea and Neath railway, afterwards amalgamated with the Vale of Neath railway. When the Vale of Neath was amalgamated with the Great Western railway, Mr. Lean was made District Engineer under Mr. W. G. Owen, then Chief Engineer of the Great Western railway, and in the year 1876 was promoted to the post of Divisional Engineer, thus having, by ability and perseverance raised himself rapidly in the profession. During his connection with the Great Western railway, he, in connection with the other engineers of the Company, received, through Mr. W. G. Owen, the thanks of the Directors for the care and general supervision used in the conversion of the gauge from broad to narrow in the year 1872. He was a member of the South Wales Institute of Engineers, and on the 6th of March, 1866, he was elected an Associate of the Institution of Civil Engineers. He published a small work on 'Railway Curves,' with formulæ and useful tables for setting out switches and crossings; also the 'Practical Platelayer's Guide.' Although he was a thorough

practical man, he excelled most as an engineer of permanent way. He died rather suddenly at Neath on the 17th of December, 1877, in the sixtieth year of his age, from disease of the heart.

MR. ALEXANDER CLUNES SHERRIFF[1] was a native of Aberdeen, and at an early age he obtained an engagement in the railway service. For some time he was Goods Manager on the Northern railway at Hull. In 1856 he was appointed General Manager of the Oxford, Worcester, and Wolverhampton railway, which he succeeded in raising from a position in which it barely earned its own working expenses to one yielding some return to the original shareholders. When the Oxford, Worcester, and Wolverhampton line was amalgamated in 1860 with the Worcester and Hereford, and acquired the name of the West Midland railway, Mr. Sherriff continued as the general manager of the combined undertakings, and retained that post until their amalgamation a little later with the Great Western railway, when he retired under an arrangement with the new directorate. Shortly afterwards he was elected a member of the Town Council of Worcester, and subsequently sheriff, alderman, and several times mayor of that city. He was also one of the city magistrates. At the general election, in 1865, he was elected M.P. for Worcester in the Liberal interest. Mr. Sherriff was also chairman of the Worcester Royal Porcelain Company, and of the Oldbury Railway Carriage Company, and a director of the Patent Shaft and Axletree Company, the Metropolitan Railway Company, the Metropolitan District Railway Company, and the Metropolitan and St. John's Wood Railway Company. He took a prominent part in effecting the conversion of the Worcester City and County Bank into a limited company, and was one of the originators of the Rosedale and Ferry-hill Mining Company, founded in 1861. Mr. Sherriff was a bluff, kind-hearted, and genial man, an effective rather than an eloquent speaker, and an excellent man of business. He was a decided favourite with people at large, and especially possessed the affections of the working classes. He was elected an Associate of the Institution of Civil Engineers on the 5th of February, 1867, and died at Weybridge, in Surrey, where he had resided for several years, on the 17th of March, 1878, at the age of sixty-two.

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[1] Condensed from 'The Worcestershire Chronicle,' Saturday, March 23, 1878.

MR. EDWARD PEASE SMITH was born on the 9th of June, 1816, at Croydon. His parents belonged to the Society of Friends, and he was carefully educated under their auspices. About the year 1833, he entered the office of the Stockton and Darlington railway, after which, among other works at the commencement of his career, he was engaged, between the years 1838 to 1840, as sub-resident Engineer, upon the North Midland railway, then in course of construction near Chesterfield. It was during this period that Mr. Smith first became acquainted with Mr. J. T. Leather, Assoc. Inst. C.E., who was the contractor for a portion of the line. Mr. Smith had a good knowledge of and a taste for mechanical engineering, which led him, after an interval of a few years, to establish works at Southampton. Here his attention was devoted to marine engines, and especially to their furnaces, with a view to the durability of the boilers and the economy of coal. He was not, however, satisfied with the commercial success of his efforts in this direction, and turned his attention wholly to civil engineering.

In the year 1851, Mr. Smith undertook the charge of the Portland breakwater works, as Resident Manager for the contractor, Mr. J. T. Leather. He carried out the system of water supply for the works, by bringing the water from the south side of the island, for which purpose steam pumping power of an efficient kind was provided, and entirely arranged by him. He also isolated the Verne fortifications by a cutting in the solid rock, 100 feet wide, by 75 feet deep, and carried out other important works in scarping the Verne rock. The works of the Weymouth Waterworks Company were constructed under his supervision during this period. In 1859 he went to the Cape of Good Hope, with Mr. A. T. Andrews, M. Inst. C.E., in connection with the harbour works at Table Bay. In 1860–61, he designed and carried out the circular staging for constructing the large pier-head at the outer end of the Portland breakwater, and the fort erected upon it; and in connection therewith arranged an ingenious system of tipping the deposit, and afterwards building the masonry by means of radiating steam-girder travellers of wide span, the steam crabs upon which could command any point below them. This arrangement was subsequently used by Mr. Smith in the construction of other large works, among which may be mentioned the forts at Spithead, Gilkiker Fort, and in the works for the extension of Portsmouth Dockyard. In 1861 the contract was taken by Mr. Leather for the construction of the forts at Spithead; and the whole of the arrangements for carrying out these works, including

concrete-block making, plant, shipping pier, special barges for transport, and circular stages for the construction, were designed by Mr. Smith. In connection with the Spithead forts, it may be mentioned that not a single accident of a serious character happened throughout, and the arrangements were in fact almost perfect. A special feature in all his contrivances was the extreme care with which he provided an ample margin of safety to minimise the risk to life. In 1862, he was also engaged under Mr. (now Sir John) Hawkshaw, Past-President Inst. C.E., in the operations connected with works to remedy the failure of the St. Germain's sluice of the Middle Level drainage. Before the completion of the superstructure of the Spithead forts in the beginning of the year 1867, Mr. Smith undertook for Messrs. Leather, Smith, and Co., the charge, as General Manager, of the important works, then commencing, for the extension of Portsmouth Dockyard, and was chiefly instrumental in modifying and improving the suggested means for successfully executing that work, and he had the satisfaction of seeing the success of his arrangements. There was only one effort of any consequence connected with the works which was not entirely successful. This was an attempt to execute excavations in deep mud by means of dredging machines working from staging. It was of importance to commence this excavation, and, from the nature of the mud and its position and depth, ordinary means were inapplicable, and floating dredgers were out of the question. Complete and well-arranged dredging machines of light construction, worked by steam, were put upon travellers of 64-feet span, of nearly the ordinary pattern in use on works in which Mr. Smith was concerned, and these dredged the mud and put it into wagons at the end of the travellers, from whatever position the dredgers upon them might be, without much difficulty and very economically. But the strains upon the staging and traveller were too great, due partly to the fact that beds of peat with trees and roots were met with, and below the peat in some cases hard rock, the exact position of which was not known until it was touched by the dredger. In the end this method of performing the work had to be abandoned, and the machinery provided for it was converted into an effective means for working inclines. Though of a sanguine disposition and less careful, like many another genius, when his own affairs only were at stake, Mr. Smith possessed distinguished talents as an engineer, and was most discreet and prudent in all matters in which the interests of others were concerned. He was bold in his ideas, but always weighed carefully the probable result of any action, and spared no pains to ensure success. In works of the

magnitude of those of which Mr. Smith had charge, many difficulties of course had to be met, and his promptness and resource were on all occasions noticeable. He possessed in a marked degree the happy faculty of carrying his assistants with him in all his efforts, and was ever ready to hear and fairly consider any suggested improvement in arrangements, however differing from his own views, and frankly to give credit to those under him for what was their due. Mr. Smith had considerable experience in matters connected with diving, beyond those in which that operation had to be resorted to in carrying out the construction of works of which he had charge, as in the recovery of valuable property lost by shipwreck, and he was much looked up to for his judgment by the men he employed. His views as to the limit to which it was possible to carry diving operations usefully were very decided, and perhaps few had more experience from which to draw conclusions. Mr. Smith continued to hold the position of General Manager of the Portsmouth dock extension works till March 1876, when he finally retired in consequence of failing health. He died on the 1st of November, 1877.

Mr. Smith was elected an Associate of the Institution of Civil Engineers on the 2nd of February, 1864.

SECT. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

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1. *Adjustment of Accidental Errors of Observation in a Levelled Network of Heights.* By Herr v. BAUERNFEIND.

(Sitzungsberichte der mathematisch-physikalischen Classe der k. b. Akademie der Wissenschaften, München, vol. vi., pp. 243–270.)

2. *The Bavarian Spirit-levelling.* By Herr v. BAUERNFEIND.

(Abhandlungen der mathematisch-physikalischen Classe der k. b. Akademie der Wissenschaften, München, vol. xii., part 3, pp. 83–132.)

The method of least squares has latterly been universally accepted as the best means of adjusting accidental errors in every description of levelling. All the treatises on the subject agree in assigning similar values for correcting a given side of any network of heights if the observations are of equal weight, as, for instance, when they are assumed as inversely proportional to the lengths (s) of the levelled sides, or to the squares of the probable errors of the observed differences of level (d), but they give varying values if the weights are arbitrarily fixed by different principles, as, for instance, by so-called "practical considerations."

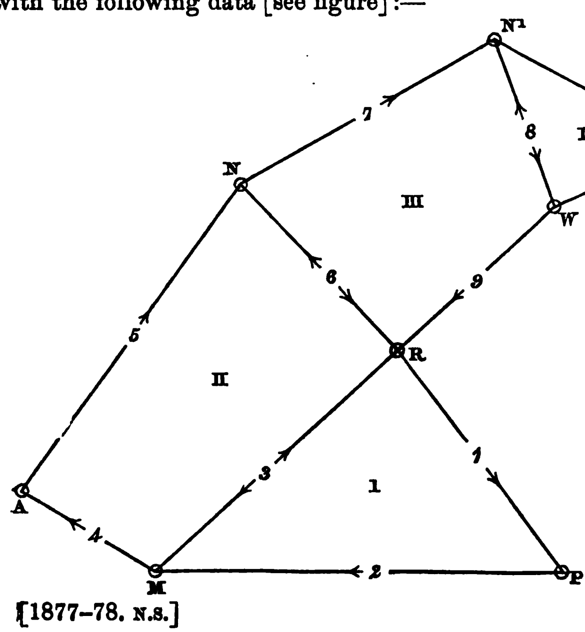
This method is, however, difficult, even when the number of polygons to be adjusted does not exceed ten, as is the case in Bavaria, and no commensurate advantage accrues from it; but it becomes an impossibility when applied to the spirit-levellings of such vast areas as Germany, France, &c. For supposing the network to consist of n interconnected polygons, there are first of all n "conditional equations" to satisfy, in order that the sum of all the rises and falls in each polygon should balance each other, and, in addition to these, there is the further condition that the sum of the squares of the errors should, from the weights assigned to them, be a minimum. Should there be then m sides in the whole network (where the common side of two polygons is only counted once in the reckoning), the corrections for these m sides must be found from m additional equations of the errors. Thus $n + m$ equations must be solved where evidently the first-named n conditional equations alone impose more or less trouble in proportion to their numbers. Consequently, in the case of extensive areas, the work must be divided into smaller portions of

at most ten polygons, and afterwards be joined together by expedients which can no longer be termed "scientific."

The method proposed by the Author is unattended by this difficulty—the labour of computation simply increasing with the number of polygons—and it fulfils all the conditions of the more accurate method save the one that the sums of the squares of the errors [vv] be a minimum, and here even it is proved by three examples that their sums are only a little greater.

Starting from the consideration that it is not fair to mar the good levelling done in any one polygon by the less accurate work in another, or to improve the latter at the expense of the former, the Author begins by adjusting whatever polygon has the greatest closing error in proportion to its perimeter, dividing this error over all the sides proportionally to their lengths. He then adjusts the adjacent polygon, which has the next greatest closing error, but in it the common side is retained as corrected from the first polygon: the closing error, therefore, of this second polygon—modified by the correction of the common side—alone falls upon its remaining sides for proportional distribution. The third, fourth, and each successive polygon which with only one side touches the already adjusted portion of the network are similarly treated, but in those connected by two or even three sides the corrections already found for such sides must in the same way be retained, the remainder only of the closing-error being distributed over the other sides in proportion to their lengths.

To compare the two methods, each is applied in turn to the Bavarian levelling network, consisting of four closed polygons with the following data [see figure]:—



Kilomètres.	Mètres.
$s_1 = 125 \cdot 771$	$d_1 = + \ 35 \cdot 8723$
$s_2 = 179 \cdot 025$	$d_2 = -217 \cdot 5062$
$s_3 = 147 \cdot 266$	$d_3 = +181 \cdot 6541$
$s_4 = \ 60 \cdot 597$	$d_4 = + \ 32 \cdot 0958$
$s_5 = 174 \cdot 047$	$d_5 = +179 \cdot 5981$
$s_6 = 101 \cdot 083$	$d_6 = - \ 30 \cdot 0005$
$s_7 = 134 \cdot 879$	$d_7 = - \ 38 \cdot 6644$
$s_8 = \ 80 \cdot 112$	$d_8 = - \ 48 \cdot 8053$
$s_9 = \ 87 \cdot 034$	$d_9 = + \ 57 \cdot 4440$
$s_{10} = \ 96 \cdot 768$	$d_{10} = -100 \cdot 1619$
$s_{11} = \ 67 \cdot 892$	$d_{11} = + \ 51 \cdot 4646$

The closing-error (Δ) of each polygon is consequently as follows:—

$$\begin{aligned} \text{No. I} &= \Delta_1 = + d_1 - d_2 + d_3 &&= +\,0 \cdot 0202 \text{ mètre.}^1 \\ \text{,, II} &= \Delta_2 = - d_3 + d_4 + d_5 - d_6 &&= +\,0 \cdot 0393 \quad \text{,,} \\ \text{,, III} &= \Delta_3 = + d_6 - d_7 - d_8 + d_9 &&= -\,0 \cdot 0252 \quad \text{,,} \\ \text{,, IV} &= \Delta_4 = + d_8 - d_{10} + d_{11} &&= +\,0 \cdot 1080 \quad \text{,,} \end{aligned}$$

The perimeters (S_{I} . . . . . . S_{IV}) of each polygon and the total length (S) of all the sides of the network being:—

$$S_{\text{I}} = 452 \cdot 062 \text{ kilomètres}, \ S_{\text{II}} = 482 \cdot 993 \text{ kilomètres},$$
$$S_{\text{III}} = 403 \cdot 108 \text{ kilomètres}, \ S_{\text{IV}} = 244 \cdot 772 \text{ kilomètres},$$
$$\text{and } S = 1254 \cdot 474 \text{ kilomètres}.$$

I. Adjustment by the Method of Least Squares.

This is effected in two different ways: (*a*) by a modification of General Bayer's method; (*b*) by Jordan's method. In the former, the weights P_1, P_2, P_3 . . . . are assumed equal to the quotients $\frac{S_{\text{I}}}{s_1}, \frac{S_{\text{I}}}{s_2}, \frac{S_{\text{I}}}{s_3}$; . . . . when ($vv$) the sum of the squares of the corrections (v) is found to amount to 49·6504 square centimètres, whence the mean error (m) of this levelling = $\pm$ 2·228 millimètres, or within the limit of 3 millimètres imposed by the General Conference on European Surveys. Jordan, however, assumes the weights to be inversely proportional to the squares of the probable errors of the observed differences of level, and marks them successively P_1, P_2, P_3 . . . . . The sum of the squares of the corrections (vv) by this method amounts to 58·9872 square centimètres.

II. Adjustment by the Author's Method.

Here, as well as in the method of least squares, the following four conditional equations exist, viz.:—

$$(1.) \quad \begin{cases} o = + (d_1 + v_1) - (d_2 + v_2) + (d_3 + v_3) \\ o = - (d_3 + v_3) + (d_4 + v_4) + (d_5 + v_5) - (d_6 + v_6) \\ o = + (d_6 + v_6) - (d_7 + v_7) - (d_8 + v_8) + (d_9 + v_9) \\ o = + (d_8 + v_8) - (d_{10} + v_{10}) + (d_{11} + v_{11}). \end{cases}$$

[1] It will be at once apparent that the circuit of each polygon is made in this case from left to right.

One great difference, however, between the two is that while in the stricter method it makes no difference in what order each polygon is adjusted, in this one it is imperative to commence with whatever polygon has the greatest closing error per kilomètre of its perimeter. Hence[1] polygon IV (the Fichtel Mountains loop) is first adjusted, else side s_8 would be retained in it as corrected from polygon III, and a very large share of the closing error (Δ_4) of IV would fall upon only the two sides s_{10} and s_{11}, thus greatly increasing (vv) the sum of the squares of the corrections, whereas Δ_4 is now divided over each of the three sides of polygon IV in proportion to their lengths.

Since the closing error Δ_4 is to be divided over polygon IV, the correction per mètre of length (Q^{IV}) is 0·0004412 mètre, and therefore the correction from each side is:—

		Mètre.	Centimètres.
$v_8 =$	$- s_8 \,.\, Q^{IV}$	$= - 0{\cdot}03535$	$= - 3{\cdot}54$
$v_{10} =$	$+ s_{10} \,.\, Q^{IV}$	$= + 0{\cdot}04268$	$= + 4{\cdot}27$
$v_{11} =$	$- s_{11} \,.\, Q^{IV}$	$= - 0{\cdot}02983$	$= - 2{\cdot}99$

Applying these in the conditional equations (system 1, No. 4), the corrected differences of level (d) become:—

	Mètres.	Mètre.	Mètres.
$d_8 =$	$+ (\ 48{\cdot}8053$	$- 0{\cdot}0354)$	$= + 48{\cdot}7699$
$d_{10} =$	$- (100{\cdot}1619$	$+ 0{\cdot}0427)$	$= -100{\cdot}2046$
$d_{11} =$	$+ (\ 51{\cdot}4646$	$- 0{\cdot}0299)$	$= + 51{\cdot}4347$

and the sum of the differences = 0, as it should be.

In polygon III the closing error $\Delta_3 = - 0{\cdot}0252$ mètre and $S_{III} = 403{\cdot}108$ kilomètres, but as the correction $v_8 = - 0{\cdot}0354$ mètre has been already applied to the common side s_8 of 80·112 kilomètres in length, and is not here to be altered, the closing error for the other three sides is only—

$$- \Delta_3 + v_8 = \underset{\text{Mètre.}}{0{\cdot}0252} - \underset{\text{Mètre.}}{0{\cdot}0354} = - \underset{\text{Mètre.}}{0{\cdot}0102}$$

to be apportioned by the equation—

$$Q^{III} = \frac{\Delta_3 + v_8}{S_{III} - s_8} \times s = \frac{0{\cdot}0102}{322{\cdot}996} \times s = 0{\cdot}000032 \times s.$$

The corrections from s_6, s_7, s_9 therefore become—

$$v_6 = - 0{\cdot}33 \text{ centimètre}, \quad v_7 = + 0{\cdot}42 \text{ centimètre},$$
$$v_9 = - 0{\cdot}27 \text{ centimètre},$$

and the corrected differences of level (system 1, No. 3):—

$$d_6 = + 29{\cdot}9972 \text{ mètres}, \quad d_7 = - 38{\cdot}6686 \text{ mètres},$$
$$d_9 = + 57{\cdot}4413 \text{ mètres},$$

and these, added to the difference of level of the 8th side, $- d_8 = - 48{\cdot}7699$, give zero, and prove the polygon balanced.

[1] The magnitude of the closing error in polygon IV is supposed to be due to an error of 1 decimètre in levelling s_{10}.

In polygon II, since $\Delta_2 = + 0\cdot0393$ mètre and $v_6 = - 0\cdot0033$ mètre, then by system 1, No. 2, $- v_3 + v_4 + v_5 = 0\cdot0426$ mètre, to be apportioned by the equation—

$$Q^{II} = \frac{\Delta_2 + v_6}{S_{II} - s_6} \times s = \frac{0\cdot0426}{381\cdot91} \times s = 0\cdot000111 \times s;$$

whence follows as before:—

$$v_3 = + 1\cdot64 \text{ centimètre}, \quad v_4 = - 0\cdot68 \text{ centimètre},$$
$$v_5 = - 1\cdot94 \text{ centimètre}.$$
$$d_3 = - 181\cdot6705 \text{ mètres}, \quad d_4 = + 32\cdot0890 \text{ mètres},$$
$$d_5 = - 179\cdot5787 \text{ mètres}.$$

Adding these to $d_6 = - 29\cdot9972$, the result is zero, and polygon II is balanced.

In polygon I, $\Delta_1 + v_3 = + 0\cdot0202$ mètre $+ 0\cdot0164$ mètre $= + 0\cdot0366$ mètre $= - v_1 + v_2$ (system 1, No. 1), to be apportioned by the equation—

$$Q^{I} = \frac{\Delta_1 + v_3}{S_{I} - s_3} \times s = \frac{0\cdot0366}{304\cdot796} \times s = 0\cdot00012 \times s;$$

whence results as before:—

$$v_1 = - 1\cdot51 \text{ centimètre}, \quad v_2 = + 2\cdot15 \text{ centimètres},$$
$$d_1 = + 35\cdot8572 \text{ mètres}, \quad d_2 = - 217\cdot5277 \text{ mètres},$$

the sum of d_1, d_2, d_3 giving zero, as before.

It is easily seen that the sum of the differences of level both of the circumscribing figure as also of every other junction of two or three polygons will now also equate to zero.

From the above corrections (v) and their squares it is shown that the sum of the latter (vv) by this method amounts to $53\cdot8810$ square centimètres, as against $49\cdot6504$ by the more accurate method, the mean error (m) now being $\pm 2\cdot279$ millimètres per kilomètre, or only $0\cdot05$ millimètre greater than by the latter, a difference not appreciable. Had the polygons, however, been adjusted in the order I, II, III, IV, the sum of the squares of the corrections (vv) would then amount to $66\cdot8372$ square centimètres. No explanation can as yet be positively given why vv by this method is smaller than the same obtained by Jordan's, unless this be due to the different method of weighting the observations, but, at any rate, it is not owing to any error in the computations. To prove still further that his results are not fortuitous, the Author gives *in extenso* the computations by his method of two other levelled networks which have been already adjusted by the method of least squares: 1. A Prussian network of General von Morozowicz, where the mean error (m) per kilomètre only differs by $\pm 0\cdot007$ millimètre; 2. A Baden network of Dr. M. Doll, where again no appreciable difference exists, and where the differences in the corrected levels only range between $0\cdot4$ millimètre and $3\cdot3$ millimètres. The

Author consequently urges that his method, which is based on a sound principle, not only saves time, but also offers greater advantages the more polygons there are to adjust, while at the same time it gives equally good results as the stricter method.

Some interesting statistics are added in the "Abhandlungen" about the levelling itself, and a report promised on a suggestion that additional bench-marks should be chosen so as to show, after the lapse of centuries, any changes in the level of the ground. This suggestion is now being tested on rocks by means of porcelain bench-marks, but the Author considers permanent buildings, &c., best suited for the end in view.

E. H. C.

NOTE.—A strange discrepancy exists in the value of m as given in the two works under notice, and deduced by the Author from the method of least squares. In the "Session Reports," $m = \pm 2 \cdot 601$ millimètres, while in the "Abhandlungen" it is only $2 \cdot 228$ millimètres. Independent calculations prove the accuracy of the latter. Again, the Author gives m by his own method as $\pm 2 \cdot 709$ millimètres, while it really amounts only to $2 \cdot 279$ millimètres as given above.—E. H. C.

The Preservation of Wood. By C. A. OPPERMANN.

(Bulletin mensuel de la Société des anciens Élèves des Écoles nationales d'Arts et Métiers, vol. x., p. 272.)

After reference to the three principal causes of decay of timber—viz., 1st, rotting due to moisture, mould, and parasitic vegetation; 2nd, fermentation of the saps, causing dry-rot; 3rd, attacks by worms—the Author dwells upon the physical constitution of wood generally, and gives the following figures as the percentage of water in wood freshly cut in about the middle of the first half of the year:—Hornbeam, 18·6 per cent.; willow, 26·0; maple, 27·0; true service, 28·3; ash, 28·7; birch, 30·8; European nettle-tree, 32·3; English oak, 34·7; English oak butt, 35·4; fir, 37·1; horse-chestnut, 38·2; pine, 39·7; beech, 39·7; alder, 41·6; aspen, 43·7; elm, 44·5; red deal, 45·2; lime-tree, 47·1; Lombardy poplar, 48·2; larch, 48·6; white poplar, 50·6; black poplar, 51·8.

From these it will be seen that the weight of water in fresh felled timber varies in different species from one-fifth to one-half the total weight. A large quantity of this is rapidly given off by evaporation to the atmosphere, but as equality approaches between the hygroscopic state of the atmosphere and the moisture of the wood, drying takes place very slowly, and can never be complete; timber thoroughly air-dried hardly ever containing less than from 15 to 20 per cent. of water. As showing the difference in the density of various woods in different states of dryness the following table is given (see next page).

In considering the chemical composition of wood generally, the Author gives a very complete table of analysis, from which it

SPECIFIC GRAVITY of WOOD in DIFFERENT STATES of DRYNESS.

Name of Wood.	1 Freshly cut.	2 Air-dried.	3 Oven-dried.
English oak	1·0754	0·7075	0·7441
White poplar	0·9859	0·4873	0·4464
Beech	0·9822	0·5907	0·5422
Elm	0·9452	0·5474	0·5788
Hornbeam	0·9452	0·7695	..
Larch	0·9205	0·4735	..
Sylvester pine	0·9121	0·5502	0·4205
Maple	0·9036	0·6592	0·5779
Ash	0·9036	0·6440	0·6137
Birch	0·9012	0·6224	0·5699
True service	0·8993	0·5440	..
Fir	0·8941	0·5550	0·4303
Red deal	0·8699	0·4716	0·3838
European nettle-tree	0·8633	0·5910	..
Horse-chestnut	0·8614	0·5749	..
Alder	0·8571	0·5001	..
Lime-tree	0·8170	0·4390	0·3480
Black poplar	0·7795	0·3656	..
Italian poplar	0·7634	0·3931	0·4402
Willow	0·7155	0·5289	..
Guaiacum wood	..	1·3420	..
Ebony	..	1·2260	..

may be gathered that the mean composition is for each hundred parts:—

	Carbon.	Hydrogen.	Oxygen.
Wood, various	49·83	6·23	43·89
Cellulose	43·69	6·24	50·07

The quantity of ash obtained on burning wood depends upon the part of the tree from which it is taken, the following being the average quantity obtained from the wood of different forests:—

Wood from lower part of trunk	1·23 per cent.
„ „ upper „ „	1·34 „
„ „ main branches	1·54 „
„ „ small „	2·27 „

In wood which has remained a long time in water in transport from forest to sea, the quantity of ash is slightly increased, the carbon slightly decreased, oxygen proportionately increased, and specific gravity decreased.

Reference is made to the rotting of wood in different ways by oxidation in atmospheres of different degrees of humidity, and of purity depending on ventilation, and the Author then describes several modes of artificially preserving timber, some of which have already been referred to in these volumes,[1] after which he describes M. Victor Fréret's system of preservation, consisting in

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xliv. p. 322.

obtaining the complete desiccation of the wood in stoves or ovens in which the smoke from the wood fires heating the stoves is allowed to circulate, and from which the vapours arising from the drying wood are allowed to escape. By this means it is claimed that a natural absorption of a combination of pyroligneous acid and creosote takes place in the wood; the acid and the creosote being supplied by the wood smoke. All sap and water are said to be driven out of the wood, and its weight reduced by 35 to 40 per cent., and the cost of the process, when the stoves, which are described, are once obtained, is given as from about 1·17*d.* to 1·4*d.* per cubic foot. Freshly cut oak of about a foot in thickness may be preserved in about eight days, and deal or fir in about five days, the method of drying not causing, it is stated, any splitting or warping of the timber.

W. W. B.

On the Nature of Elastic Limits and their Method of Alteration.

By Prof. R. H. Thurston.

(Dingler's Polytechnisches Journal, vol. ccxxv., p. 233.)

The Author, in reply to the remarks upon his former Papers, contained in the articles by General Uchatius (vol. ccxxiii., p. 242) and Professor Bauschinger (vol. ccxxiv., p. 1), states, in a concise form, the nature of the quantities defined by him as primitive or original and normal elastic limits of metals under strains, and shows that in the so-called iron class an increase of the normal elastic limit is possible, but not in those of the tin class. The process adopted by General Uchatius is defined to be a method for the alteration of the original, but not of the normal elastic limit, which latter change the Author considers, from the result of his experiments, to be an impossible one in bronze and similar alloys. This process is considered to be substantially the same as the Dean process introduced in America in 1869, and subsequently recommended for adoption by the Committee on Indian Field Artillery. The use of metal moulds for bronze guns was also recommended by Mallet in 1856, and the method of cold rolling, by which metals are similarly modified, was introduced by Bernard Lauth in 1857–58. The plan of subjecting the tie-rods of the roof of the Crystal Palace at Munich to a strain before setting them up, noticed by Professor Bauschinger as adopted by Werder in 1854, is also shown to have been recommended by Clark in his work on the Britannia and Conway bridges in 1850. Finally, the Author points out that the graphic method of representing the behaviour of materials under strain was admitted by General Morin in 1850, and that to him the credit of having originated this method of investigation must be attributed.

H. B.

An Apparatus for Measuring the Strains on Iron Constructions.

By M. Dupuy.

(Annales des Ponts et Chaussées, 5th series, vol. xiv., p. 381.)

The object of this apparatus is to ascertain, by direct measurement of the alteration in length of the different parts of iron bridges when loaded, whether the actual strains correspond to those indicated by theory. The arrangement of the apparatus is based on the fact that a bar of iron is elongated or shortened by a ten-thousandth part of its length under a strain of tension or compression of 1·27 ton per square inch of section. To the bar to be tested a fulcrum pin is bolted on which works a lever arm, one end being twenty times as long as the other, and terminating in a pointer travelling over a graduated arc carried by the fulcrum piece; to the short end of the lever is jointed one end of a bar 1 mètre (3·28 feet) in length, a pin in the other end of which is also secured to the piece under examination. With the proportions above given, each millimètre (0·039 inch) of movement on the scale corresponds to one kilogramme of strain per square millimètre of section.

Experiments with the apparatus were first made on single bars of iron, then on a girder specially constructed for the purpose of measuring the strains on the braces, and lastly on some railway bridges. The results of these experiments, of which graphic representations are given, indicate that the actual strains do not differ much from those assigned to them by theory, and in no case exceed the maxima limits, thus affording a satisfactory verification, as far as they have gone, of the correctness of the formulæ employed for calculating them. Also it should be noted that a strain exists which tends to increase or diminish the distance between the flanges according as the load is placed below or above the girders, and it is consequently necessary to avoid reducing considerably the braces at the centre of the girder; moreover, as the braces bear only a portion of the shearing strain, and the remainder has to be borne by the flanges, it is important that the flanges should not be greatly reduced at the abutments where the shearing strain is greatest. The strains also produced on the braces of the same panel are not equally distributed between the braces in tension and compression, and the flanges have a tendency to overturn. The Author enters at some length into a theoretical investigation of the causes of the differences observed between the calculated and actual strains.

L. V. H.

On Walls to Resist the Pressure of Water. By M. PELLETREAU.

(Annales des Ponts et Chaussées, 5th series, vol. xii., p. 356, 1 pl.; vol. xiv., p. 258, and p. 480, 3 pl.)

Two hypotheses are adopted, which, without being strictly correct, serve as a starting-point, so that the results obtained may be comparable with previous investigations in which these hypotheses are accepted. 1. A wall subjected to the pressure of water, resists merely by its weight, without any strain of flexion. 2. A force acting obliquely on a section of the wall produces the same crushing strain which the resultant normal to the face would produce. Three conditions have to be satisfied:—Resistance of the wall to crushing under its own weight; resistance to crushing under the pressure of the water; and, lastly, resistance to sliding. The section of the wall, moreover, must be made as small as is consistent with the fulfilment of these conditions within the limits of safety. Walls resting upon a solid foundation, and walls resting upon a soft foundation, or a foundation exposed to scour, have to be considered separately; and walls may be classed under three heads:—1. Top of wall level with the surface of the upper water. 2. Top considerably below the ordinary level of the upper water. 3. Top above the upper water level.

The Author commences with the investigation of the conditions of resistance of a wall resting on a solid foundation, and where the top is level with the surface of the upper water. He divides the wall into four zones for different heights, and investigates, by elaborate analytical methods, the profiles suitable for each, and gives graphic representations of some of the results obtained—the valley across which the wall is placed being supposed indefinitely large.

Comparing the section of a dam erected near Ajaccio with the section it should have, according to the formulæ given in the article, it appears that, whilst the section as built amounts to 203 square yards, the theoretical section, taking the actual top width of 19 feet 8 inches, would be 161 square yards; whereas, reducing the top width to 6½ feet, which would be quite sufficient, being the actual top width of the dam at the sides, the required sectional area would be reduced to 128 square yards.

The alterations that may be made in the profile of a dam, when the valley is narrow and the reaction of the sides affords support to the wall, are next fully discussed.

When the top of a dam is level with the surface of the upper water, its theoretical width at the top is zero; but with high dams a moderate width at the top does not materially modify the theoretical profile. When, however, for the purpose of obtaining a roadway, the wall is raised considerably, and its width also notably increased, changes occur in the theoretical profile which form the subject of a special investigation. The profiles of dams whose summits are liable to be submerged are next considered. Such

instances are found in dams across steep narrow valleys, enclosing torrential rivers with a considerable fall below the dam, and where, accordingly, the dam may have to sustain the pressure of a considerable flood above, without much counteracting support of a rise of water in the part of the river below. This last investigation terminates the branch of the subject relating to walls on solid foundations; the case of walls resting on soft or unstable foundations being reserved for a future article.

L. V. H.

On the Frictional Resistances of Pneumatic Foundations.

By A. Schmoll.

(Zeitschrift des Vereines Deutscher Ingenieure, October 1877, p. 433.)

In applying pneumatic foundations for bridge piers, it is important to know the amount of frictional resistance encountered by caissons in various strata and at different depths, in order to determine the load necessary to overcome this resistance, or, in case of light, insufficiently resisting soil, to determine the depth to which a pier must be sunk to carry the load.

Cast-iron cylinders, or caissons with casements, can be detached from the chains by which they have been kept in position as soon as the columns have well penetrated the ground, whereby the sinking proceeds quicker, and the quantity of loose earth, forced under the lower edge of the caisson into the excavating chamber, is considerably reduced. For the erection of four cylinders of the Kehl bridge over the Rhine, where no cofferdams were used, the quantity of sand and stone removed from the interior of the excavating chamber was about 21,000 cubic yards, while the space occupied by the subterranean portion of the cylinders was only 13,734 cubic yards, the difference arising from the influx of loose earth and sand into the excavations.

According to the experience of the Author, not only the nature of the soil but also the shape of the column influences the frictional resistance, the latter being smaller for cast-iron cylinders and rectangular caissons than for caissons of an oblong section.

The details given relate to the application of cast-iron cylinders or of wrought-iron riveted caissons with vertical sides and with casings reaching above the water level for strata which form the bed of the Seine, Rhine, and Danube. In determining the frictional resistance, the following conditions must be observed:—

1. The tube or caisson must be vertical.
2. It must be free on all sides, neither attached to the guide chains nor resting upon its lower edge, but only kept in equilibrium by its weight, by the friction on its circumference, and by the internal air pressure.

To achieve these conditions, the total weight of the cylinder must be less than the frictional resistance plus the weight of the

displaced water; or else sinking takes place without air being let off, and without the cutting edge being undermined. If these conditions be fulfilled, the air pressure shown by a gauge is recorded, the safety valve opened, and after the sinking motion of the caisson has begun, the air pressure is again observed and the valve rapidly closed. The beginning of the motion indicates that the effective air pressure, together with the friction at the circumference of the caisson, have become slightly smaller than the total weight of the cylinder.

Experiments on Co-efficients of Friction.

As co-efficients of friction relating to materials and surfaces which occur in pneumatic foundations were unknown to the Author, he determined the following by direct experiments made in March 1876 in Vienna with the aid of a dynamometer.

Description of Materials.	Co-efficients of Friction.			
	At the Beginning of Motion.	During the Motion.	Beginning of Motion.	During Motion.
	For Dry Materials.		For Wet Materials.	
Sheet iron without rivets on gravel mixed with sand	0·4015	0·4583	0·3348	0·4409
Sheet iron with rivets on gravel and sand	0·3965	0·4911	0·4677	0·5481
Cast iron (unplaned) " "	0·3677	0·4668	0·3646	0·4963
Granite (roughly worked) " "	0·4266	0·5368	0·4104	0·4800
Pine (sawn) " "	0·4088	0·5109	0·4106	0·4985
Sheet iron without rivets on sand . .	0·5361	0·6313	0·3655	0·3247
" with " " . .	0·7269	0·8391	0·5156	0·4977
Cast iron (unplaned) " " . .	0·5636	0·6063	0·4744	0·3796
Granite (roughly worked) " . .	0·6473	0·7000	0·4728	0·5291
Pine (sawn) " . .	0·6633	0·7340	0·5787	0·4793

Each figure is the average result of at least ten experiments. Between two consecutive experiments there was an interval of from eight to ten minutes. All materials were rounded off at their face in sledge shape and drawn lengthwise and horizontally over the gravel or sand; the latter was well levelled and bedded as solid as it is likely to be in its natural position. The riveted sheet iron contained twenty-five rivets on a surface of $2 \cdot 53 \times 1 \cdot 67 = 4 \cdot 22$ square feet, the rivet heads were half round and of $\frac{13}{16}$ inch diameter.

Contrary to the experience of General Morin with other materials, it follows from these experiments that for the above-named rough materials the resistance of friction from rest is smaller than the resistance during the motion.

As the Author's experiments relate to materials with rough surfaces, this remarkable fact can be explained by the supposition

that during the motion the small cavities and depressions on the sheet-iron, cast-iron, wood, and stone surfaces become filled with dry sand which adheres to the surface, so that the effect is nearly the same as though two surfaces of dry sand were in contact with each other.

But for the friction of the surfaces of the same materials (except granite) on wet sand the reverse occurs. The friction during the motion is smaller than the friction at the beginning of motion. Probably the wet sand forms a more solid bed for the wet bodies sliding over it, in consequence of which the small depressions of the latter are not filled with sand so easily as in the case of dry surfaces.

Calculation of the Resistance of Friction in Pneumatic Foundations.

First example: Experiments made on the 2nd of June, 1863, with the upper part of column V of the railway viaduct over the Seine at Orival near Elbœuf. As soon as the cast-iron cylinder, standing in an extensive and rather uniform bed of gravel, and having ceased to move for thirty-two hours, completely fulfilled all conditions necessary for such an experiment, and was undermined about 6 inches, the workmen left the column and the safety-valve was opened. When the air pressure had sunk from 1·20 to 1 atmosphere above the normal pressure of the atmosphere, the cylinder began to move, and at once sank 13 inches. It would have sunk deeper if the experimenter had not arrested the escape of air by closing the safety-valve at the beginning of the motion. At the moment of sinking the water had risen in the lower ring to a height of 34 inches.

Some minutes after this first experiment a second and third was made with the same cylinder, when it sank 13 inches and 12·6 inches respectively, the total fall for the three consecutive experiments therefore being 38½ inches.

The weight of the column, including iron, concrete, masonry, and woodwork, was 218 tons.

The loss of weight by immersion at the moment when friction was overcome and the column began to sink was—

$$[(10{\cdot}20 \times 10{\cdot}1788) + (1{\cdot}00 \times 10{\cdot}3491) - (0{\cdot}87 \times 9{\cdot}7868)] \times 1000 = 105{,}659 \text{ kilogrammes (104 tons)},$$

10·20 mètres being the height of the immersed part of the column including the lowest ring, and 10·1788 square mètres the superficial area of the cylinder (diameter = 3·6 mètres, and circumference = 11·31).

Mètres.

$\left.\begin{array}{l} 1{\cdot}00 \;\;\;\;= \text{height} \\ 10{\cdot}3491 = \text{superficial area} \end{array}\right\}$ of the lowest ring.

9·87 = height of inner water level over the cutting edge.

9·7868 = superficial area of water in the lowest ring.

The resistance of friction was therefore—

$$222{,}231 - 105{,}659 = 116{,}572 \text{ kilogrammes (114 tons).}$$

The Author further cites (example 2) an experiment with the first caisson of the right abutment of the railway bridge over the Danube between Vienna and Stadlau (Austrian State railway), 5th of November, 1868, the results being nearly the same as in No. 1.

It sometimes occurs that, when the cylinder is in clay soil, the water does not enter into the working chamber, although the compressed air may have been completely left out. This was the case in experiments made by the Author during the sinking of the cylinder mentioned in example No. 2, on the 31st of December, 1868, and on the 2nd and 4th of January, 1869. If the sinking of the caisson, in consequence of a decrease of the pressure of the air in the interior, has begun, and the water fails to enter into the working chamber, the loss of weight by immersion is determined in two ways, first, by multiplying the air pressure per unit remaining in the interior of the caisson, with the base of the caisson; and second, in assuming that the water column replaced by the sinking object has only a height equal to the vertical distance of the surface of the clay from the external water level.

Of the two calculated results, the larger one is considered to be the buoyancy or loss of weight of the immersed object, and to be deducted from the total weight of the latter, the difference being the resistance of friction.

The 3rd example cited is an experiment made with No. 1 column (right bank) of the bridge over the Danube near Stadlau, on the 4th of January, 1869. The total weight of the sinking column was 1,305 tons. The cylinder began to sink when the air pressure had fallen from 1 atmosphere to 0·85 atmosphere, and in consequence of a further escape of air it gradually sank in one minute 18½ inches. The caisson being in a layer of solid clay of 3·73 feet thickness before it began to move, the water failed to enter into the cylinder.

The weight of the displaced water column, taking its height 27·35 feet, was 594 tons, and the upward pressure of the compressed air inside the cylinder was 625 tons. Deducting the latter result from the total weight of the caisson, the frictional resistance on the surface of the cylinder is 678 tons. The column was sunk into the soil to a depth of 18·76 feet.

If the water fails to enter into the working chamber after a complete escape of the compressed air, the upward pressure is represented by the weight of the displaced water, taking as its height the vertical distance of the external water level from the water-tight soil, and the amount of frictional resistance is obtained by deducting this pressure from the total weight of the object.

The examples from which the Author obtained his results are recorded in a series of tables, which show clearly that, in homo-

geneous strata, the resistance per unit of frictional surface decreases with the increasing depth. From this it is to be concluded that the density and cohesion of these strata augment with increasing depth, and therefore the pressure upon the sides of the column becomes less than in the upper strata.

A. H.

Results of Experiments on the Expenditure and Loss of Air in Pneumatic Foundations.[1] By A. S. von Eisenwerth.

(Zeitschrift des Oest. Ingenieur- und Architekten-Vereines, 1877, p. 196.)

The object of these experiments was to ascertain the amount of air actually required for sinking wrought-iron caisson foundations by the pneumatic method. A rough rule, determined by practice, was that for a caisson having an area not exceeding 800 square feet a blower capable of delivering about 12,000 cubic feet of air per hour was sufficient: but it was desirable to investigate the question more closely, and advantage was therefore taken of the construction of several large bridges with which the Author was connected. Owing to the inherent difficulties of the experiments, they were not very numerous, and were made at depths not exceeding 34 feet. The old practice was to estimate the number of workmen and the number of candles that would be employed inside the caisson, to reckon 220 cubic feet per workman, and 11 cubic feet per candle per hour, cast up the total, double it to allow for losses by locking, leakage, &c., and take this as the amount of air to be supplied. It was found, however, that only 17 to 40 per cent. of the air pumped in for the benefit of workmen actually reached them, and also that the most opposite opinions prevailed as to the quantity of air which a man really consumed. In addition, the whole method was vitiated by the fact that with the best workmanship the loss by leakage was so great as to compel the pumps to be always kept at work, and hence the supply was in all cases ample for the purposes of the workmen. Hence the loss by leakage determined the supply, and the only proper method was to investigate this.

The leakage through the air-pipes, air-lock, and shaft was small in comparison with that through the walls of the caisson, and was also readily detected and stopped to a considerable extent by plastering the joints on the inside with clay, which was forced into the crevices by pressure, and assisted to keep the whole air-tight. Again, the roof of the caisson, covered first with a layer of cement, and then a thick mass of concrete, was practically air-tight, except at its edges, where it joined on to the vertical sides. Thus the leakage through these sides, in spite of the masonry with

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxvii., p. 275.

which they are lined, was by far the most important. It was found that during the first expulsion of the water from the caisson, when it acted as a seal, preventing any escape from the bottom, the leakage through the sides alone caused a loss equal to from 20 to 330 (*sic in orig.*) per cent. of the air theoretically required, according to the goodness of the workmanship. When the sinking was over, and the excavation in progress, the air pressure frequently drove the water altogether out of the caisson, and then there was a great escape of air round the bottom edge which had to be added to the leakage through the sides.

Table I. of the Paper shows the losses observed in various experiments during the expulsion of the water. The final results are given in two columns, of which the first shows the volume of atmospheric air lost during the filling of the caisson, taking the theoretical pressure due to the head of water in each case, while the second shows the volume, taking the actual pressures as given by the manometer, both being per hour per square mètre of the walls of the caisson. Both cases of course include the air required to overcome all resistances of friction and cohesion. The figures in the first column are the larger, but the difference is small, and on the whole a fair average appears to be 2·892 cubic mètres per square mètre of wall-surface (9·487 cubic feet per square foot) lost in each working hour.

Table II. gives results of experiments on the expenditure and loss of air while the caisson is being sunk by excavation inside. In this table the variations in volume of air arising from the differences of temperature inside and outside of the caisson have not been taken into account, as they do not greatly affect the main result. The loss of air (or the expenditure less that used in the air-lock and in the sinking) is given per hour in three ways: (1) per square mètre of bottom area; (2) per lineal mètre of perimeter; (3) per square mètre of side surface. In (1) and (2) the differences between the different caissons are so great that no law can be deduced—the quantities varying under similar conditions to an extent of 46 per cent. But when the height is taken into account, as in (3), this difference is reduced to 17½ per cent., and the results are far more uniform. Leaving out two caissons, which appear to have been exceptional, the loss per square mètre of side area per hour varied between 3 and 5¼ cubic mètres (9·843 and 17·225 cubic feet per square foot), according to the workmanship of the caisson and the nature of the soil. In coarse gravel and clay the loss was decidedly less than in fine gravel and sand, being on an average about 4 cubic mètres (141·26 cubic feet) in the first case, and 4⅓ cubic mètres (153 cubic feet) in the second, for a medium depth of about 7 mètres (23 feet). Where the caissons are small, the relative loss is greater, because the blower pumps more air than is necessary, and part, therefore, escapes under the bottom edge; in this case, by an arrangement of valves, two caissons can be sunk together with the same blowing engine. As might be expected, the loss of air increases with the increasing

depth of the caisson under water, the average increase being apparently about 1 cubic mètre per mètre depth (10·76 cubic feet per foot). Table II. also gives the means of separating roughly the loss due to leakage through the walls, pipes, &c., from that due to escape under the bottom edge; for the losses with the same caisson can be compared (1) while the water was being forced out, and there was therefore no escape from the bottom; and (2) while the excavation was proceeding, and this escape going on, allowance being made as above for any increase of depth in the latter case. Three such comparisons give the proportion of loss due to escape from the bottom as 41, 45, and 23 per cent. respectively of the whole, the loss per hour per lineal mètre of the perimeter being on the average 4·25 cubic mètres (45·5 cubic feet per foot). It is evident that in the last case the caisson was unduly leaky, and 43 per cent. may thus be taken as about the proportion for the loss by escape from the bottom. Generally the striking result is shown that in caisson foundations the proportion of air used for passing the materials and workmen through the air-lock, and for keeping the caisson full of air against the increasing pressure as it descends, is only 1 per cent. of the whole, the other 99 per cent. being lost either through leakage or escape from the bottom.

W. R. B.

Foundations of a Bridge over the Ruhr at Düssern.

By Herr Wiebe.

(Zeitschrift des Architekten- und Ingenieur-Vereins zu Hannover, vol. xxiii., p. 574.)

A branch of the Rhenish railways, lately completed, crosses the river Ruhr at Düssern, a little above its junction with the Rhine, and in the midst of an alluvial flat, which, on the right bank especially, is overflowed to a considerable distance in time of flood. To allow for this, the bridge, in addition to three river arches of 157½ feet span, comprises nine flood arches (one on the left bank, the rest on the right), each of 51 feet span. The river openings are crossed by iron arched girders without hinges, carrying a superstructure on which the railway is laid: the flood openings are arched with masonry. The velocity of the river at the highest floods was taken to be 8·69 feet per second.

For the foundations of the river spans, piles were driven so as to form cofferdams round the sites of the land and river piers, and of the left-hand abutment: these sites were then excavated by steam dredgers and filled in with concrete and masonry. For the other spans on the right bank the excavation was made roughly without the aid of cofferdams, and filled in with concrete tipped from above.

The workshops and erecting yard were situated on the right

bank, as there much the greater part of the work was to be done. The stone and other materials were conveyed by barges to the site and unloaded by a crane on to wagons standing on a temporary wooden jetty, whence they were conveyed by a line of railway, laid with a slight fall, to their place in the building yard. Goods coming by land to the left bank were brought over the river by a chain ferry boat worked by the current. The cost of these preliminary works, including the setting up of mortar mills, lime-kiln, concrete stages, &c., was about £1,000.

Previous borings had shown that the soil for about 4 feet below the bed of the river was gravel and sand, and that below this greensand extended to a great depth. For the flood piers on the right bank the excavation was carried on in the height of the summer, and consequently almost entirely in the dry. The excavation was let to a sub-contractor at about 4*d.* per yard above water, and 8*d.* below water to a depth of 3 feet, exclusive of transport of spoil, which was paid for on a schedule. For the other piers the excavation was performed by vertical steam dredgers worked from a gantry, except in the case of the river pier No. 2, which was in the middle of the stream, and for which a floating dredger was employed. The machinery, &c., was provided and handed over to a sub-contractor, who paid all working expenses, and had to deliver up the plant in good condition at the end of his contract. The prices per cubic yard, including a lead on land of 55 yards, were 10*d.* per yard with the floating dredger, and with the vertical dredgers 14*d.* for soil or gravel, and 3*s.* for greensand. The work of the floating dredger was rendered very slow and expensive by the extreme tenacity of the greensand; and in consequence the excavation was stopped at a depth 3 feet 3 inches less than was originally intended, it being considered that the foundations were amply secured by the ring of piles and by an embankment of stones. The vertical dredgers worked with far greater ease, and raised on an average 140 cubic yards per diem as against 27 with the floating dredger. The total cost of the dredger excavations for one abutment of four piers was about £700; and of the excavation for the seven flood piers and one abutment about £169.

The piles of the cofferdams were driven by steam pile-drivers, mounted on stages which were supported on piles previously driven by hand. A separate starling was fixed up-stream to guard the cofferdam of pier No. 2 from the collision of coal barges coming down on the rapid current of the Ruhr. The piles were driven in bundles of four, tied together by three iron hoops, and these bundles were subsequently united to each other by strong strap-bolts. For the other piers the ground was levelled and the stage founded upon it. The pile-drivers were of the Nasmyth pattern, raising the monkey by the direct action of the steam, and, when all went well, delivered seventy-five blows per minute. The weight of the monkey was 2,240 lbs., and the fall 3 feet 6 inches. At river pier No. 1, where the soil was tenacious, and many piles gave

way in driving, old rails were tried as a substitute to complete the circuit, and were found to answer well, being easy to drive, and sufficiently firm when driven. The piles had been ordered for economy only 8 inches square, which was found insufficient in hard ground. In other cases, where the soil was favourable, about 5 feet length of piling was driven per diem. The total cost of the piling for river pier No. 2 was about £800, and for No. 1, £350. The other dams cost considerably less.

Before commencing the concrete and masonry work, careful experiments were made as to the strength of the cements and limes procurable in the district. Tables of these are given in the Paper. The increase of bulk of hydraulic lime, when slaked, was also tested, and found to be in the proportion of 2·2 to 1. This was when care was taken that the whole was reduced to powder, so that in ordinary practice a rather smaller proportion must be looked for. The weight of the fresh burnt lime was ascertained to be 55 lbs. per cubic foot, that of the slaked lime 35 lbs. per cubic foot in its powdered state. Rich lime (non-hydraulic) gave 51 lbs. per cubic foot in the first case, and 82·5 lbs. per cubic foot in the latter.

Mortars made from various mixtures of sand with lime (both common and hydraulic) were also tested for bulk and weight. With all ordinary proportions the bulk of the mixture was about two-thirds that of the ingredients before mixing, and its weight about 116 lbs. per cubic foot. The mixture generally used for the concrete was made of equal parts of slaked lime (hydraulic), trass, and sand. A cubic mètre of the concrete was made out of 0·54 of this mortar, 0·45 of broken stone, and 0·405 of gravel. For the land piers and abutment the concrete was simply tipped into the excavation until it came above the lower water level, and the masonry was then built in the dry upon the foundation thus laid. For the remainder (except river pier No. 2) it was tipped through a shoot carried on a travelling stage, and brought up to the level of low water; whilst in pier No. 2 (which was in the middle of the stream) the masonry was commenced at about 7 feet below the lowest water level. The cost of this concrete, deposited in place, amounted to 14*s.* per cubic yard, of which 2·3*s.* were for mixing and laying, 0·8*s.* for mixing mortar, and the remainder for materials. The total cost of the concreting for the river piers and left bank abutment was £1,300, that for the flood piers on the right bank £526.

On these concrete foundations was laid rubble masonry of rough stone, in mortar of the same composition as for the concrete. The mortar was not allowed to exceed one-fourth of the bulk of the masonry, and the stones were not to fall short of 1 square foot in area of bed, or 4 inches in thickness. This masonry cost about 12*s.* per cubic yard, of which 2*s.* were for labour, the rest for materials. For the whole bridge the total cost was about £1,177. Above this courses of cut stone were commenced. The piers were in all cases embanked round with loose stones to fill up the excava-

tion, and form a support for the masonry against floods. These stones were specified not less than 25 lbs. in weight, and were carefully laid. The cost of this stone embankment for the whole bridge was about £449.

The total cost of the foundations for the whole bridge was £7,218. If taken per square foot of base (the base being taken to be the area of a horizontal section through the lowest course of cut stone), the cost was about 22*s.* for the river piers and those on the left bank, and 8*s.* for the piers on the right bank, where the work throughout was of a lighter character.

W. R. B.

The Kentucky River Bridge.

(Scientific American, Supplement, iv., 1503–1505.)

The Kentucky river at the point where it is crossed by the Cincinnati Southern railway is about 300 feet in width, and flows in a tortuous cañon from 1,000 to 1,300 feet in width, with a depth varying from 300 to 450 feet. The greatest rise in floods above low water was 57 feet, with a velocity at the site of the bridge of 8 miles per hour. Owing to the frequent passage of lumber rafts (twenty per hour during freshes), and the fact that the river takes a sharp bend under the bridge, a pier in the waterway was considered inadmissible, and it was decided to construct the bridge of three spans, each of 375 feet, two of the openings being over the land and the centre one over the river. The great height, 275 feet above low water, rendered the erection of staging for the land spans costly, while the frequency of floods made it impracticable for the river span. It was consequently decided to build the girder out from the rocks on each side, with the assistance of a temporary timber pier in the centre of each land span. It was foreseen that on the completion of the erection and the closure of the centre span, the rise and fall of the iron piers due to change of temperature producing variations in the strains on the members would render it expedient to break the continuity of the beam. It was thus decided to hinge the beam by cutting the lower boom of the end spans at a distance from the piers equal to one-fourth of the span; when completed, it would thus be a continuous beam for a length of 525 feet, 75 feet of which at each end overhung the piers, and supported one end of the 300-foot length reaching to the rock abutments. The truss is of the Whipple type, 37·5 feet deep and 18 feet wide, carrying the rails on the top; each span being divided into twenty bays of 18·75 feet each. The two piers are carried up in masonry to a height of 71 feet, being 120 by 42 feet at the base; on these are built the iron piers tapering from 71·5 feet by 28 feet at the base to 18 feet by 1 foot at the summit, and terminating in a pin which carries the truss. The

erection was effected as follows:—After the bridge seat was cut out of the rock, the end posts were put in position, their tops being bolted back to the masonry towers, previously built by Roebling for a suspension bridge, and their lower ends touching powerful screwjacks laid in the line of the bottom booms, and abutting on the rock. The first section of the bottom boom and first diagonal were built on, then the next post and first section of the top boom, thus completing the first bay, the weight being supported by the tension of the anchorage bolts to the Roebling towers and the compression on the screwjacks. In this manner the truss was built out from the abutment until the limit of the available resistance of the anchorage was reached. In the meantime a temporary timber pier was being built at a distance of 196 feet 10 inches, measured from the shore end to its centre. When the end of the truss was landed on the temporary pier, the four truss posts resting on it were raised by screwjacks until the anchor bolts on the rock were relieved of a certain determinate portion of their strain, and the truss was then built out to meet the permanent pier now being carried up at a distance of 178 feet 2 inches from the temporary pier. When the truss and pier met, owing to the coldness of the weather and the compression of the lower boom, the span was somewhat too short, as had been anticipated. To overcome this difficulty, the entire pier, weighing 400,000 lbs., was moved on rollers towards the span until the pin which connects the two could be put in place. This done, the truss was built out as before, until the centre of the river was reached. When the two extremities of the bridge had been built out as described, and the last two bays completed, it was found that gaps existed between the two of 3 inches and 2 inches in the upper booms, and of 4 inches and 5 inches in the lower. By the use of the screwjacks at the shore ends, and by moving the piers towards each other, the gap of 2 inches was closed, the gap in the other top boom still remaining open. To close this, use was made of the horizontal bracing between the two top booms of the truss, the diagonals tending to draw together the ends of the booms still unclosed were tightened up while the thermometer was at 70° in the sun, the counter diagonals being slackened. The contraction of the diagonals closed the gap at daybreak the next morning, with a temperature of 40°. The top booms were now riveted up, leaving gaps in the lower booms of 2 inches and 3 inches.

The contraction due to temperature had by 4 A.M. next morning withdrawn the shore ends of the lower boom $\frac{3}{4}$ inch from the screwjacks. These were screwed out to take up the space, and by midday the expansion had closed the gap in one boom, and by repeating the operation the next day both were riveted up, and the girder made continuous from shore to shore. It only remained now to sever the lower booms at the previously determined points, so as to hinge the girder; this was effected by driving out temporary rivets inserted during erection for that purpose. The mean motion of the joint after cutting amounted

to only $\frac{5}{16}$ inch, and the change of profile of the bridge was hardly perceptible.

In manufacturing the iron for the bridge, special mixtures were used in puddling and piling, every plate was tested, and bars paired together according to their moduli of elasticity. The moduli varied from 20,400,000 to 28,200,000, and in spite of all precautions the trusses began to vary in height during erection after three bays had been put in place, the variation exceeding an inch in several places. The piers and span are pinned together, and no allowance is made for expansion and contraction, but the additional stresses from the alteration of span due to temperature have been determined, and the requisite additional section given to the piers, while the variations in bending moment from the rise and fall of the latter have been annulled by the severance of the lower booms. In the spans there are 2,855,379 lbs. of iron, in the piers 798,901 lbs., and of masonry 12,935 cubic yards.

The erection was commenced October 16, 1876, and the bridge completed on February 20, 1877, the number of men employed not exceeding sixty.

The bridge was tested with a train of engines and trucks of iron, giving an equivalent uniform load of 2,073 lbs. per foot on the 300-foot spans, and 1,977 lbs. per foot on the 375-foot span with the following results:—

Both end spans loaded.	Inches.
Greatest deflection of 300 feet span	1·518
„ „ „ cantilever point	1·944
„ depression of pier	0·372
Upward deflection of mid span	2·832

Mid span loaded, ends unloaded.	Inches.
Greatest deflection of mid span	3·498
Upward movement of cantilever point	1·580

The longitudinal stability of the truss was tested by running a train of twenty-four trucks loaded with iron on to the bridge at a speed of twenty-six miles per hour, and bringing it to rest in a distance of 104 feet by the application of the brakes and reversing the engine, when the extreme motion of the pier heads amounted to only $\frac{1}{2}$ inch. During the trials it was found that the longitudinal motion, where the lower boom was cut, was $1\frac{1}{2}$ inch.

A. T. A.

On Light Auxiliary Railways, laid upon Common Roads.

By E. Heusinger von Waldegg.

(Organ für die Fortschritte des Eisenbahnwesens, vol. xv., p. 31.)

The Author advocates, for districts unable to support ordinary railways, the construction of light lines laid on existing roads, thus

saving the whole expense of land, earthworks, bridges, culverts, &c. The feasibility of this has been shown by the Broelthal railway, 20 miles long, laid down in 1864, and by the Cassel and Wilhelmshöhe tramway, lately opened. The former, built only as a goods line, now conveys passenger trains at 10 miles an hour round curves of 112 feet radius and over gradients of 1 in 36. In the latter there are gradients of 1 in 16·6, and curves of 164 feet radius; and the trains, at their ordinary speed of 6 miles per hour, can be stopped in a length of 6 feet. In neither is any fencing or watching of the line found necessary. Such lines, where the road is good and wide, and the terminus on an existing railway, should be of standard gauge; but where the radius of curves is less than 200 feet, and the width of road less than 26 feet, they should be of mètre gauge (3 feet 3⅜ inches) or less. There is no inconvenience to passengers in the break of gauge; and even for goods the cost of transhipment is less than generally supposed. The Broelthal Railway Company only charge 2½ Pf. per centner (3*d.* per ton) for such transhipment. But this cost may be reduced almost to nothing by using for the light railway, instead of the ordinary 'box' truck, a platform truck fitted with loose boxes, in which the goods can be packed and shifted. Such boxes, made of sheet iron, with doors at both ends hinged at the bottom, have come into extensive use. Their dimensions are about 6 feet by 2 feet 4 inches by 3 feet 10 inches high, having a capacity of about 2⅜ cubic yards, and can be used for almost any kind of merchandise, even sheep and cattle, if fitted with wooden rails, padded inside; they rest on four cast-iron wheels, about 12 inches diameter, which run on cross rails, bolted to the truck platform. By means of these the boxes can be easily run by one man off the trucks of the light railway on to those of a standard railway, or *vice versâ*, or they can be drawn singly along a road by a horse. This, for coal, &c., where shifting and breakage is to be avoided, is a great advantage. In addition goods of any description, and from different senders, can be conveyed together on the same wagon, thus economising the number of trucks.

The Author recommends that the railway should, in general, be laid at the side of the road, so as not to interfere with it, and should consist of steel rails, laid on trough-shaped, wrought-iron longitudinal sleepers, resting on gravel or stone ballast. The lines should be single with crossing places at certain stations. The locomotives should be separate from the wagons, and should have capacious boilers, with large steam space and heating surface; the tubes should be horizontal, not vertical, to hinder the escape of sparks. In towns coke should be the fuel, and the locomotive should be closed in and roofed over so as to look as far as possible like an ordinary omnibus. The exhaust steam should be partly condensed and utilised in heating the feed water, partly led into the chimney and allowed to escape through holes in a ring-shaped pipe, in order to assist the draught.

The following is an estimate of the cost of such a railway:—

——	Standard Gauge.	Mètre Gauge.
	£.	£.
Permanent way, per mile	1,300	1,130
Ballasting and laying ditto per mile	210	180
Set of points and crossing, chilled iron	21	19
Water-tank, with pump and well, about	225	210
Locomotive, 40–60 HP.	600 to 750	..
„ 20–50 HP.	..	500 to 600
Passenger car, 1st and 2nd class	250	200
„ „ 3rd class	225	175
Covered goods wagon	145	120
Open platform „	90	75
Iron box on wheels	15	15

W. R. B.

Normal Dimensions for (Italian) Railway Plant and Fittings.

(Giornale del Genio civile, An. xv., p. 621.)

A Commission, appointed by the Italian Minister of Public Works, under the presidency of Signor F. Biglia, sat in Florence in the month of November, 1877, in order to inquire whether any modifications were desirable in the general rules for railway dimensions which had been established in 1871. The Commission drew up a series of regulations of which the following is an abstract:—

1. Distance between the internal faces of the tires. The gauges of the different lines over which the same vehicles are intended to run vary from 55·56 inches to 57·10 inches, with variations of 0·12 inch, more or less. The Commission proposes that the normal distance between the internal faces of tires shall be 53·535 inches, with a margin of 0·078 inch for new stock, and with a margin of 0·156 inch more, or 0·117 less for old material.

2. The normal diameter of the wheel tires is fixed at 59·19 inches; the conical taper varying from $\frac{1}{16}$ to $\frac{1}{20}$. Wheels will be allowed to run of a diameter not less than 50·01 inches, provided that they are placed not less than 53·535 inches apart.

3. The normal width of flange is to be 1·18 inch; the minimum allowable, if the tire is not less than 4·71 inches wide, being 0·866 inch.

4. The normal depth of flange is to be 1·26 inch. A maximum depth of 1·50 and a minimum depth of 0·98 inch are the extreme variations allowed.

5. The minimum thickness of tires is fixed at 0·787 inch, when the wheel is not fitted with a brake; and 0·866 inch when it is so fitted.

6. The gauge between the rails is determined at 56·90 inches, which is intermediate between the German gauge of 56·55 inches and the French gauge of 57·10 inches.

7. The maximum increase of gauge on curves is to be 0·59 inch; so that the maximum allowable gauge will thus be 57·49 inches.

8. The interval between the rail and the guard rail, on level crossings, shall not be more than 1·57 inch on a straight line, and 2·97 inches on a curve.

9. Triple switches, as sources of great danger, are prohibited on the lines of main traffic.

10. In stations and crossings it is proposed to tighten the gauge to the width of 56·51 inches, and to limit the space left open for the passage of the flange to 1·57 inch.

11. The minimum distance between two tracks of rails is to be 83·48 inches.

12. The minimum distance between the axles of any two pairs of wheels is to be such as to allow the vehicle to run round a curve of a radius of 305 yards.

13. The width of goods platforms is fixed at 14·76 feet, and that of passenger platforms at 18 feet.

14. The normal height above the rails for the centre of the buffers is fixed, for an empty vehicle, at 3·41 feet, and the limit, when the carriage is loaded, is 3·016 feet. The normal diameter of the buffer heads is 13·68 inches; the horizontal distance, from centre to centre, is fixed at 63·73 inches. The minimum diameter of buffer head admissible is 11 inches. The limits of variation in height are, 42·13 inches for an empty and 37 inches for a loaded vehicle; those in width are from 65·86 inches to 69·70 inches, but any deviation from the normal width of 67·73 inches is to be compensated by a corresponding increase of the minimum diameter of 11 inches.

15. A normal template, or profile, showing the extreme dimensions of any part of any vehicle admissible on a railway is attached to the Report. The extreme height, which is required for only the width of 3 feet 6 inches in the centre of the profile, is 14·20 feet. The extreme width is 10·16 feet, but a slight taper is allowed above the height of 12·13 feet. A clearance of 5·9 inches is to be allowed between the outline of the normal template and any part of any structure on a railway.

16. Another template is provided to show the extreme projection allowable for the under side of any locomotive, or other vehicle, as referred to the line of rails.

17. The normal height of the station platforms is fixed at 9·8 inches above the rails. The side wall of the platform is not to be within 31·42 inches of the nearest rail.

18. In the goods stations, the height of the platform is fixed at 41·34 inches above the level of the rails, and the clearance of the side wall is to be 34·56 inches.

19. The length of the couplings of vehicles is fixed at from 31·5 to 33 inches, when completely open, for goods wagons, and from

37·7 to 38·5 inches for passenger carriages. The distance between the inside of the hook and the outside of the buffer is to be 12·17 inches in the first case, and 15·71 inches in the second.

20. Safety chains are to be provided of defined lengths and diameters.

21. It is prescribed that the handles of brakes shall all turn in the same direction, from left to right.

22. In case of projecting cabins for the guards being placed at the end of any vehicles, they must be protected by a proportionate lengthening of the projection of the buffers.

The regulations are signed by Signor Biglia, as President of the Commission.

F. R. C.

The North-Western Railways of Spain.

(Revista de Obras publicas, Nos. 8 to 13, Madrid, April to July 1877.)

Two very important lines of railway, connecting the provinces of Gallicia and Asturias with the centre of Spain, belong to the North-Western Railway Company. They run from Palencia, in Old Castile, to the seaports of Corunna and Gijon on the Bay of Biscay, and have a combined length of 455 English miles, of which 271 are now open to traffic, and 184 are still in construction.

The Author gives a detailed description of the works on each line.

A. Gallician Railway.—Section 1. *Palencia to Leon*, 76 miles, 20 chains.—At Palencia the line connects with the Santander railway at a short distance from the main line from Madrid to Irun and France. The ground is nearly level throughout; the earthworks are moderate, and, with a few short interruptions, all the gradients are easy. The only works of importance are nine girder bridges, one over the river Esla, 310 yards in length, with nine openings, each of about 34½ yards; a bridge over the river Carrion of 80 yards, another of 55 yards over the river Cea, and six smaller bridges. There is a handsome station at Leon, and workshops in which carriages and wagons are built, and where also several of the iron bridges were made. This section was opened to traffic in November 1863.

Section 2. *Leon to Brañuelas*, 50 miles.—In this section the ground is also nearly level; there is a wrought-iron girder bridge, of 105 yards, over the river Orbigo, divided into four lengths, but, owing to the waterway being insufficient, one end has been twice washed away, and a brick arch, 6½ yards span, has recently been added. Over the river Tuerto there is a second girder bridge, 55 yards in length. This section is also open to traffic.

Section 3. *Brañuelas to Ponferrada*, 30 miles.—Here the railway enters the mountains, rising at first and then falling with an average gradient of 1 in 66, and maximum 1 in 50. At about

1½ mile from the station of Brañuelas, the main watershed which separates the rivers Douro and Minho is traversed by a tunnel 594 yards in length, after which the line runs along the mountain side overlooking the river Tremor, on a descending incline of 1 in 50, with heavy rock cuttings, and twelve tunnels in the first 5½ miles, varying in length from 77 to 676 yards. It then leaves the valley of the Tremor, entering the Silva valley, which it follows along the left bank, but presently winds back again along the right bank, returns into the Tremor valley through another tunnel, 1,100 yards in length, which crosses under the before-mentioned incline at a much lower level, so as to form a complete figure of 8, and then runs down to the bank of the river, passing from one side to the other six times. At Vitoria the Tremor discharges its waters into the river Boeza, which is crossed by a bridge of 38 yards span. The succeeding seven or eight miles are over easy ground, until the line reaches San Miguel de las Dueñas, whence to Ponferrada—5 miles of the heaviest work of this section—the railway has been completed to formation level. On this section there are altogether thirty tunnels, measuring 4 miles and 432 yards in length, of which more than half have yet to be perforated. The bridges are mostly composed of wrought-iron girders, in lengths of 22 yards, and the railway is in many cases supported on the mountain-sides by walls built of masonry, some of which are of great height.

Section 4. *Ponferrada to Quiroga*, 52¼ miles.—At Ponferrada the Boeza joins the Sil, and after crossing the latter river by a 33-yard bridge, the railway follows its banks for 9 miles over easy and moderately level ground as far as Villa de Palos, but here the Sil is joined by two other streams called the Cua and Burbia, and each of these three rivers requires a bridge 100 yards in length, besides numerous smaller bridges and large culverts over some minor affluents, and the whole are connected by a series of high embankments, which are rendered necessary in order to keep the railway out of reach of the frequent floods. After leaving Villa de Palos, the river Sil has a most tortuous course through gorges where the rocks rise almost perpendicularly to a height of from 800 to 1,000 feet. Between Villa de Palos and Entomar, a length of less than 20 miles, the railway crosses the Sil six times at a considerable elevation, and requires twenty-three tunnels, some of which are from 500 to 800 yards long, besides a number of short bridges and viaducts, which cross the gorges high above the water level, as well as many deep cuttings in rock. There follow about 10 miles of lighter work from Entoma to Petin, and then again the banks of the river Sil contract, and the remaining 14 miles to San Clodio (Quiroga) require nine tunnels, a bridge over the Sil at Novaes, 165 yards long, three small iron bridges, and a great many large culverts, besides numerous very deep rock cuttings and elevated retaining walls.

Sections 5 and 6. *Quiroga, viâ Monforte, to Lugo*, 93 miles, 60 chains.—In this section the railway has to cross two watersheds,

that which separates the Sil from the river Cabe, and that between the Cabe and the Sarriá, which is an affluent of the river Minho. The line follows the left bank of the Sil for about 4 miles, and then, by means of an iron girder bridge 180 yards in length, crosses it obliquely to the right bank, which it follows only as far as the confluence of the river Lor with the Sil. Here it leaves the Sil, and commences to rise towards the watershed up the valley of the Lor. This river is crossed at an elevation of about 70 feet, by a bridge 150 yards long, and there follow seven smaller bridges, three considerable viaducts, and ten tunnels, before reaching the summit or first watershed, which is ultimately passed by means of another tunnel 970 yárds long. The descent from thence to Monforte does not require any important works. Between Monforte and Sarriá (28 miles) the works are much less heavy, but they include seven tunnels, one of which is 880 yards in length. The direction of the line across the watershed between the Cabe and the Sarriá rivers has not been definitively settled, and consequently this part of the section has not been yet touched. From Sarriá to Lugo (22 miles) the ground is not unfavourable, but the works include four bridges, respectively 50, 40, 22, and 17 yards long, and an imposing viaduct over the Chanca valley, near Lugo, 97 feet in height, which is composed of twenty arches, each of 34 feet span.

Section 7. *Lugo to Corunna*, 71 miles, 70 chains.—This section was opened to traffic in October 1875, but the works are still unfinished, some of the banks being too narrow, and the slopes of many of the cuttings in clay are in a dangerous condition, and require much easing. There are eight short tunnels, the longest of which is 466 yards from end to end; eleven iron bridges, maximum length 105 yards; and thirteen stations, most of which, especially that at Corunna, are still in a very incomplete and backward state.

B. Asturian Railway.—Section 1. *From Leon to Busdongo*, 33 miles, 60 chains.—This section of the railway is open to traffic. The line follows the valley of a small river called the Bernesga; for the first 15 miles, as far as La Robla, the valley is open, the works are light, and the gradients easy, rising throughout towards the elevated summit of the Cantabrian mountains. After passing La Robla, the valley becomes narrower, and the course of the river is very tortuous. The railway crosses it fourteen times on iron girder bridges, varying from 33 to 100 feet in length. At Villamanin, 28 miles from Leon, the line leaves the river Bernesga, and follows the course of a small stream as far as Busdongo, which is close to the entrance of the tunnel under the summit of the Pajares Pass.

Sections 2 and 3. *From Busdongo to La Pola de Lena*, 33 miles, 40 chains.—This, as projected, is probably the most difficult and expensive piece of railway in Europe. The Pass of Pajares is about 5,500 feet above the sea at Gijon, which is distant only about 40 miles. Between the summit and the river, the course of

which the railway must of necessity follow in order to reach La Pola de Lena, there is an abrupt fall of 2,145 feet in a distance of only 3,303 yards; the surrounding mountains are of the most rugged, rocky, and broken description, and in order to make the descent with gradients not exceeding 1 in 66, and curves with a maximum radius of 330 yards, the original project prepared by the Government engineers between the summit and the bottom of the pass at Puente de los Fierros, wound about the mountain sides for a distance of 46½ miles, and required one hundred and twelve viaducts and large bridges, besides tunnels of the aggregate length of 13 miles 890 yards. Subsequently, gradients of 1 in 50 having been allowed, a fresh survey was made, and received the sanction of the Government in 1873, by which the descent was accomplished with a length of railway diminished to 26 miles 360 yards; but there are now, in this shorter distance, seventy-six tunnels of an aggregate length of 14 miles 1,470 yards, the one under the Pajares summit being 3,330 yards long, besides many miles of retaining walls and seventy-seven viaducts, of which eighteen are under 50 feet in height, nineteen of an elevation varying between 50 and 70 feet, fourteen between 70 and 85 feet, sixteen between 85 and 100 feet, nine between 100 and 140 feet, and one of which the height exceeds 140 feet. These 26 miles of a single line are estimated to cost £56,000 per mile. The concession was originally granted with a subvention of £28,000 per mile, but a very large addition was afterwards made to it.

From Puente de los Fierros to La Pola de Lena the works are not quite so heavy. The distance is 6 miles, 1,540 yards; the railway follows the course of the river Pajares, with gradients varying from 1 in 50 to 1 in 90. There is one viaduct at Puente de los Fierros 110 yards long and 70 feet high; another at Congostinas, 55 yards long and 60 feet high; a third over the Nareda, 74 yards long and 57 feet high, and a bridge over the Pajares or Lena river, 33 yards long and about 24 feet above the level of the water. There are also on this portion seven tunnels, measuring together a total of 1,122 yards.

The Author compares this passage of the Cantabrian mountains with the three other passages over the same chain, viz., the first on the North of Spain railway (between Irun and Madrid), the second on the Tudela and Bilbao railway, and the third on the Alar and Santander railway, in order to show that the works on the Asturian line are by far the heaviest. The maximum gradient required on the Northern line in the passage of the Cantabrian chain is 1 in 66; there are twenty-three tunnels, of an aggregate length of 6 miles and 990 yards, the longest of which measures 3,250 yards, and two viaducts, one at Saleras, which is 132 yards long and 70 feet high, and one at Ormaistegui, 330 yards long and 144 feet high. On the Tudela and Bilbao line the pass has required only four tunnels, measuring together 650 yards; the earthworks are heavy, and there are thirty-nine bridges and viaducts, but they are all of very moderate dimensions. On the Santander

line the gradients in general exceed 1 in 66, and the maximum of 1 in 50 is reached on a length of 5,335 yards between Reinosa and Santiurde. There are heavy cuttings and banks, some of which are as much as 82 feet deep, but the total length of the tunnels is only 4 miles and 396 yards, and there is only one considerable viaduct, that at Celada, the height of which is 80 feet.

From these facts he draws the conclusion that it is doubtful whether the traffic which may be expected from the Asturian line warrants the construction of such an extraordinarily expensive railway, and questions whether it would not be better to adopt some more economical plan. If this had been done at first, he says, the Asturias might long since have enjoyed the advantage of railway communication with the rest of Spain.

Section 4. *From La Pola de Lena to Gijon*, length 39 miles, 30 chains.—This section is open to traffic, but much of the work is still unfinished, and the stations generally are very incomplete. The railway follows the river Pajares or Lena, which a little further down takes the name of Caudal, and, being tortuous and much confined between rocks, six tunnels were required at the bends of the river. The line crosses the Caudal two miles below the iron works at Mieres (built by an English company in 1843–45) by a wrought-iron girder bridge, 82 yards long, with three openings, resting on tubular abutments. At about 14 miles below La Pola de Lena, the Caudal discharges its waters into the river Nalon, which is crossed by the railway by means of another 82-yard bridge similar to that over the Caudal. Leaving the valley, the line then rises to Oviedo, the capital of the province, over hilly ground requiring three tunnels, together 1,384 yards in length, and descends again on the other side to the banks of the river Nora, over which is a 28-yard girder bridge, from whence to Gijon the ground offers no serious difficulties, although two considerable viaducts have been deemed necessary, one at Selguera, with twelve arches, each of 43 feet span, and the other at Serin, with eleven arches, also of the same span. The principal works of art on this section are twelve tunnels, four viaducts, five large river bridges, twenty-four road bridges over or under the line, and numerous smaller bridges and culverts. At the Port of Gijon great works are projected by the Government, but have not yet been commenced, and the railway remains for the present unconnected with the harbour.

By a law of the Cortes of January 8, 1877, the several lines are ordered to be completed at various dates, the latest being June 30, 1881.

O. C. D. R.

On Rack Railways for Steep Gradients. By R. Abt.

(Organ für die Fortschritte des Eisenbahnwesens, vol. xv., p. 1.)

This Paper gives the particulars of eight railways which are now in operation on Riggenbach's system, surmounting steep gradients by means of toothed wheels on the locomotive, gearing into a rack fixed on the road-bed. Four of these are tourist lines for summer traffic; one is partly of this description and partly used for carrying stone, and the remaining three are mineral lines only. These last have steep gradients, worked with rack-gear, for part of their length only; the remainder, where the gradient does not exceed 1 in 40, being worked by ordinary locomotives. On one—the Rorschach and Heiden railway—the same locomotive has been made to answer both purposes, an axle, which runs free when the rack gear is applied, being utilised as a driving axle on the level. All except one of these railways are of standard gauge. Two of them have the teeth spaced at 3⅛ inches, and are intended for a working strain of about 3 tons; the other four have the teeth at 4 inches, for a strain of 6 tons. In the one case the rack weighs 97 lbs., in the other 110 lbs. per lineal yard, including fastenings. The former weight includes a cast-iron saddle, which takes the ends of each pair of rack segments, and rests on two cross-sleepers.

Details of each railway are subjoined. The earliest in date (partly opened in 1871) is that from Vitznau, on the Lake of Lucerne, to the Rigi-Kulm.[1] It has a maximum gradient of 1 in 4, and a total length of 4·3 miles, with curves of 162 yards radius. The total capital account (including cost of ten locomotives, twelve carriages, and four goods wagons) is at the rate of £27,760 per mile. The train consists usually of one locomotive and one carriage, and the cost of working is 10*s.* 10*d.* per train mile. The Kahlenberg railway near Vienna is a double line, 3·1 miles in length, with a maximum gradient of 1 in 10. The capital account, including cost of rolling stock, stands at £55,600 per mile; and the cost of working is 3*s.* 7*d.* per train mile. The Schwabenberg railway, near Pesth, has a length of 1·8 mile, and a maximum gradient of 1 in 10. Its capital account, including rolling stock, stands at £27,300 per mile; and the cost of working is 9*s.* 7*d.* per train mile. The Arth and Rigi railway has a total length of 6·7 miles, of which length all but ⅞ of a mile at the beginning is rack-railroad, with a maximum gradient of 21 in 100. The capital account stands at £35,200 per mile, and the cost of working is 6*s.* 1*d.* per train mile. The Rorschach and Heiden railway has a length of 3·3 miles, and a mean gradient of 7·1 in 100. The capital account stands at £25,800 per mile, including rolling stock; and the cost of working, 7*s.* 2*d.* per train mile. The other railways are mineral lines of

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxvi., p. 103.

much cheaper construction. The most important is that at the Wasseralfingen mines, for conveying ore and slag. It is 1·1 mile long, with a maximum gradient of 7·87 in 100, and curves of 132 yards radius. The cost, including the rolling stock (one locomotive and sixteen wagons), was £7,700 per mile. The engine makes five trips per day, and the cost of conveyance is 6*d.* per ton, including interest on capital.

W. R. B.

On the Construction of Mineral Lines.

By F. GAMILLSCHEGG.

(Wochenschrift des Oest. Ingenieur- und Architekten-Vereines, vol. ii., pp. 219 *et seq.*)

Before describing the three mineral railways which form the staple of this Paper, the Author discusses the general theory of such lines, and concludes that on the continent of Europe, where mines are almost universally situated in mountainous districts, a narrower gauge than the usual one of 4 feet 8½ inches should be adopted, in order to save earthworks by employing sharper curves. He then examines the theoretical proportions which should exist between the radius of a curve, the superelevation of the outer rail, the widening of the gauge in curves (invariably adopted in Germany), and the width of the tires. He points out that in every curve the outer wheels have to move through a longer distance than the inner ones, and that therefore sliding must ensue unless the coning of the tires comes into play by, in fact, increasing the diameter of the outer wheels. The limit at which this obtains he finds to be, in railways of ordinary gauge, and with engine wheels of 39 inches diameter, a radius of 13 chains; while in the case of express engines, with 7-foot wheels, sliding must commence with a radius of 18¾ chains. He assumes the tires to have an inclination of 1 in 16, and arrives at his results by simple algebraical calculations. In the case of a line with a gauge of 30 inches, the least radius to avoid sliding would be 4½ chains, but economical motives have induced much smaller radii to be used; and the Author contends that in the case of a radius of 1 chain, which is not unusual, the theoretical superelevation of the outer rail should in reality be 10 inches, and the widening of the gauge 3 inches, both dimensions being quite impossible. Even in this case, however, only one of two axles of a truck would adopt the true radial position; the second would be parallel to the first, and therefore not radial; hence the flange of the inner wheel will grind against the rail, and the outer wheel will not run on a larger circle than the inner one, but rather the reverse. Sliding would therefore not be avoided, and the only remedy suggested for it is to diminish the gauge as much as possible, to make the wheels very small, and, if possible, to allow them to turn on the axles on one side of the trucks so as to adapt themselves to the various radii. To avoid violent rolling and

shaking of the trucks, the Author recommends the axles to be as near each other as possible, for he calculates that for a radius of 2 chains and the above gauge of 30 inches, this distance should not exceed 3 feet 6 inches.

After alluding to the various gradients adopted, and pointing out that a maximum gradient of 1 in 20 is not at all too much for a mineral line in which the traffic of loaded trucks goes down hill, and that it is better to run up or down such a gradient with easy curves than on a gradient of 1 in 25 with very sharp ones, the Author proceeds to give some details of the narrow-gauge mineral line constructed between Szekul and Resisza on the Hungarian lines of the Austrian State Railway Company. This was formerly a tramroad, but was altered in 1874 for locomotive traffic, with which it has been worked ever since. It carries coals from the collieries to the main line and ironworks at Resisza. The gauge is 3 feet, the width of formation level 9 feet 10½ inches, the smallest radius is 1⅘ chain, the weight of the rails (of Bessemer steel, Vignoles section) 36 lbs. per yard; they are fished and spiked to the sleepers without chairs. The sleepers are 5 feet 6 inches long, 7 inches broad, and 4½ inches thick; the ballast is 10 inches thick. The gauge is widened by 1⅓ inch in the sharpest curves, the outer rail being superelevated 2¼ inches.

The locomotive is four-wheeled, coupled, the distance apart of the axles being 4 feet 8 inches. It weighs 12 tons, works up to 40 HP. with a pressure of 150 lbs. per square inch, has 220 square feet heating surface; the diameter of cylinder is 9¼ inches, and the length of stroke 12½ inches; the diameter of the driving wheel is 30½ inches.

The wooden trucks are four-wheeled; the Bessemer steel axles are 3 feet 7½ inches apart; the diameter of the cast-iron wheels is 2 feet 1¼ inch, their weight being 1 ton 17½ cwt., and the net load 4½ tons. The conversion of the road into a railway and the purchase of rolling-stock cost 13,831 florins or, at 12½ florins to the pound, about £1,100 per English mile.

The mineral lines from Tavaun to Gronard and Moranzy to Agincourt (in France) are together 8½ miles long. The gauge is 39⅓ inches; the formation 6 feet 11 inches wide; the sharpest radius is 1½ chain; the distance apart of the truck-axles is 6 feet. Considerable sliding takes place in the sharp curves, when the outer wheels have in fact to travel over 10 per cent. more ground than the inner ones. The steepest gradient is 1 in 13·3, and in fine weather the engines take up 9·7 tons gross load, in wet weather only 7·5 tons. Friction varies between $\frac{1}{5\cdot4}$ and $\frac{1}{7\cdot6}$, and the locomotives weigh 7½ tons with coal and water. Their driving wheels are 2 feet 6 inches in diameter, and the two axles (coupled) are 4 feet apart. The rails weigh 27 lbs. per yard, and the cost of this line was £1,707 per mile, of which less than a quarter was required for earthworks and bridges.

In 1874 the Author had charge of the construction of the Eibenthal mineral line, which connects the collieries of Ujbanya (Banat) with

the shipping station on the Danube. The works being in the hands of private persons possessed of but a limited capital, the line had to be constructed with all possible economy, while it appeared absolutely indispensable to substitute a railway for the carts which had hitherto carried the coals to the river, and which were not able to convey more than 4,000 tons per annum, 30,000 tons being the minimum output which could pay. The distance between the two extreme points is 9½ miles, and the difference of level 1,420 feet. The smallest possible dimensions were adopted, viz., 1 chain for the radii, 2 feet 6 inches for the gauge, and 3 feet 3¼ inches for the distance apart of the axles. As a watershed had to be crossed, a gradient of 1 in 20 had to be adopted over a length of 4½ miles. The formation level was fixed at 7 feet 3 inches, but in a long cutting, where the line is horizontal, it is increased to 13 feet to afford space for a ditch with a good fall on each side. The slopes of all cuttings and banks in earth are 1 to 1, cuttings in friable rock 1 to 2, and in firm rock 1 to 6. Although the colliery is in the Tipovitza valley, which is a tributary to the Danube, it was found impossible to follow this natural line on account of the fall of the lower half, viz., 1 in 10; the railway, therefore, leaves it at Eibenthal, and passes by a tunnel 44 yards long into the upper end of the Resisza valley, whence it descends to the Danube by the Ljubortina valley.

The line commences in the sandstone of the coal measures, then crosses a stratum of metamorphic rock about 1,000 yards thick which overlies them, and during the remainder of the route passes through serpentine, of which the favourable nature permitted the above-mentioned small tunnel to be executed without any masonry. The cost of land was comparatively low, because a great portion of the railway passes through government property, for which the Crown only received the nominal sum of about 18*s.* per acre, besides the actual market value of the timber cut down. Private property was paid for at rates of from £10 to £14 per acre, and the total expenditure under this head was £22 per mile of railway. The total excavation amounted to 122,000 cubic yards, and in consequence of the steep slope of the hills, no less than fourteen retaining walls were required. The tunnel already mentioned shortened the line by 385 yards, and proved a considerable saving, as it had not to be lined with masonry. Its cross section is 10·7 square yards, the clear height 10 feet 1 inch above the level of the sleepers, and 11 feet 5 inches above the invert, the formation having been got out with a depression in the centre to drain the tunnel. The highest point of the hill is 26 feet above the crown of the arch. A great advantage was that the line of the railway always lies on the sunny, *i.e.* the north side of the valley; the work dried very quickly and the snow soon disappeared. The prices paid for all the work were low on account of the superabundance of labour at this particular period, and the general depression of trade. Excavation, including the lead up to 27½ yards, cost from 3*d.* per cubic yard for light soil to 1*s.* 6*d.* per

cubic yard for the hardest rock requiring blasting; the average price being about 6½*d*. The tunnel cost £2 5*s*. per lineal yard.

As the line passed through very broken ground on the hill-sides, an attempt was made to avoid having to construct a culvert in every depression, by stacking loose stones right through the bank wherever there was no regular water-course; this has been so far quite successful, but still fifty-eight culverts and bridges had to be erected. Eight of the latter are entirely of timber, the abutments and wings being formed of rough 2-inch planks nailed by 6-inch spikes to piles 3 feet 7 inches apart. The girders are whole balks, 12 inches by 8 inches, to save labour, which was dearer than the timber. On straight lengths the rails were laid directly on these balks; in curves cross sleepers were used to give the necessary superelevation. Where the bank was too high for these open timber bridges, culverts of masonry were adopted; the abutments were of rough rubble, the arches of brick covered with a layer of concrete from 2 to 4 inches thick. The spans vary from 3 feet to 6 feet 6 inches. The widest bridge on the line is 29 feet 3 inches span, and is constructed with stone abutments and trussed timber girders, the latter not resting directly on the masonry, which was merely well flushed with cement, to save ashlar bed-plates. The stone was all found in the railway cuttings; the bricks were made in the neighbourhood.

The road was laid provisionally for horse traction, for which locomotives are to be substituted as soon as trade develops. There was, therefore, no occasion for any engine sheds or pumping stations; but all other works, with the exception of these and the road itself, were constructed for locomotive traffic. The temporary rails weigh 12 lbs. per yard; they rest on sleepers 2 feet apart from centre to centre, and are of iron, of the usual continental Vignoles section, $1\frac{9}{20}$ inch high, the lower flange being $1\frac{17}{25}$ inch wide. The lengths of the rails are 20 feet and 19 feet 6 inches in the straight, 15 feet and 14 feet 6 inches in the sharp curves. The fish-plates are 8 inches long, 1¼ inch wide, and ¼ inch thick, with four bolt-holes square on the outer plate and round on the inner; the bolts are $\frac{9}{25}$ inch in diameter. The corresponding holes in the rails are slotted to the extent of ¼ inch. The joint plates are 3 inches by 3⅛ inches, and ⅛ inch thick, with four spike-holes; the spikes are 3⅛ inches long, of a square section $\frac{7}{25}$ inch wide.

The points and sidings were arranged for engine traffic. The former are made of planed tongues moving on five cast-steel chairs 1 foot 10½ inches apart, which are screwed to cross sleepers. The distance between the centre of the rails was assumed at 9 feet 3 inches in the sidings, which gave an angle of crossing of 9° 8′ 52″, and a length of tongue of 9 feet 3 inches, the radius of the entrance to the siding being exactly ½ chain, and its straight length 75 yards, which would admit one engine and twenty-five wagons. In the curves the gauge is widened on the inner side only, and the outer rail only is raised. On curves of 1½ chain radius and less both widening of gauge

and superelevation were tapered off into the straight by two lengths of rails beyond the curve; in the easier curves by one only. The widening of the gauge varied from $\frac{1}{8}$ inch for a radius of 8 chains to 1 inch for 1 chain; the superelevation from $\frac{1}{4}$ inch to $3\frac{1}{4}$ inches for the corresponding radii, the gauge being 2 feet 6 inches; the distance apart of the axles is 3 feet 3 inches, and the greatest speed $7\frac{3}{4}$ miles per hour. The sleepers are 4 feet 6 inches long, 8 inches wide, and 6 inches deep, half round, the bark and splint being removed. They are adzed for the lower flange of the rails at an angle of 1 in 17 inwards. The ballast is 10 inches deep, and 5 feet 3 inches wide at the level of the sleepers; it is mostly broken stone out of the cuttings, and the lead was short.

The rolling stock at present consists of twenty coal trucks, each weighing 1 ton 2 cwt., and of a capacity of $1\frac{1}{2}$ ton. On account of the steep gradients a brake is attached to each, and the trains are put together in such a manner that one brakesman can manage two trucks. The body is of plate iron, with angle stiffeners, 4 feet $9\frac{1}{2}$ inches long, 3 feet $11\frac{1}{2}$ inches wide, and 3 feet 9 inches deep, with a cubic capacity of $2\frac{1}{2}$ yards; it tips sideways on a longitudinal axle in two wrought-iron bearings, the centre of gravity being 4 feet 3 inches above the rails. There are no buffers, the frames of the wagons touching each other. The wheels are 12 inches in diameter, and have $3\frac{1}{8}$ inches width of tire; they were made at Gran, and cost £22 10*s.* delivered at Orsova.

The proposed locomotive will be constructed to take fifteen empty trucks, or $16\frac{1}{2}$ tons, up the steepest gradient at a speed of 5 miles per hour; its working weight is to be 8 tons, and it is to develop 25 HP. at a pressure of 220 lbs. per square inch. As the heating surface required would involve very considerable overhang at each end if only two axles were used, it was resolved to have two coupled axles and one revolving trailing axle under the smoke-box. Working twelve hours per day, each locomotive is to make four trips with $22\frac{1}{2}$ tons of coal each, the trains crossing each other at the halfway siding. Two locomotives will, therefore, suffice to carry 180 tons a day, or about 50,000 tons per year.

The total cost of the line was as follows (the paper florin being assumed equal to 1*s.* 8*d.*):—

	£.	s.
1. Preliminary expenses, plans, &c.	466	12
2. Management during construction	1,411	0
3. Purchase of land	200	0
4. (*a*) Tools and plant for earthworks . . .	256	5
(*b*) Earthworks, including lead	3,313	4
(*c*) Materials for masonry and brickwork . .	738	3
(*d*) Labour ,, ,, . .	549	11
(*e*) Timber and carpenters' work	265	13
(*f*) Draining, turfing, &c.	658	8
5. (*a*) Sleepers, lead, and adzing	576	3
(*b*) Rails, fishes, joints, and spikes	2,781	18
(*c*) Laying road	227	10
(*d*) Ballast	281	12
6. Rolling stock	448	0
Total cost of the temporary line .	12,173	19

Carried forward . . . 12,173 19

Additional cost for working by locomotive power:—

	Brought forward . . .		12,173 19
I.	Alteration of road	3,239 4	
II.	Station, engine-sheds, guardhouses . . .	540 0	
III.	Two locomotives	1,280 0	
	Additional wagons	536 0	
	Total		5,595 4
	Grand total of line		£17,769 3
	Or £1,857 per mile.		

E. D'A.

On the Section of Steel Rails, as fixed for the Breslau and Freiburg Railway. By H. Fein.

(Organ für die Fortschritte des Eisenbahnwesens, vol. xiv., p. 225.)

As long as steel rails were still in the region of experiment, it was natural to retain for them the sections already in use for iron rails, especially as this facilitated the gradual substitution of one for the other. Now that they have come into general use, it is time that the section should be designed in accordance with the physical properties of the material. Of these the chief are, that whilst for wrought iron the working load may be taken at 700 kilogrammes per square centimètre for extension or compression (10,000 lbs. per square inch), and at 500 to 600 for shearing (7,100 to 8,600 lbs.), with steel the load will be 1,000 to 1,500 kilogrammes in the former case (14,200 to 21,300 lbs.), and 1,000 to 1,200 in the latter (14,200 to 17,100 lbs.). Taking the lower of the figures for steel, it would appear that its strength generally is one-third greater than that of iron, and therefore its section might theoretically be made smaller in that proportion. Practical reasons prevent this principle being completely carried out, but many railway companies have adopted it to a large extent. A drawing is given of the sections of Vignoles rail in use on six main German railways for loads of 6 to 6½ tons per wheel, and distance between the sleepers 0·9 mètre to 1 mètre (3 feet to 3 feet 3 inches). These sections are very closely alike, and give a weight of 30½ to 33 kilogrammes per lineal mètre; so that it appears a rail of 33 kilogrammes per mètre (65 lbs. per yard) is sufficient for all ordinary purposes. In designing a standard rail for the Breslau and Freiburg railway this weight was adopted; while the dimensions, as fixed from the best information, were: height, 125 millimètres (4·9 inches); width of head, 56 millimètres (2·2 inches); thickness of web, 12½ millimètres (0·6 inch); width of foot, 100 millimètres (3·9 inches). The length of the rail was fixed at 9·05 mètres (29 feet 9 inches), and the space between sleepers at about 0·93 mètre (3 feet ½ inch) from centre to centre.

The strength of this rail was calculated by the formulæ given by Professor Winkler. These formulæ are:—

$$\text{Greatest strain in tension (kilogrammes per sq. centimètre)} = \frac{188 \cdot 8\, G\, l\, e_e}{W};$$

$$\text{,, ,, compression (,, ,, ,,)} = \frac{188 \cdot 8\, G\, l\, e_p}{W};$$

where G is the load per wheel, l space between the sleepers, W moment of inertia of the section about its centre of gravity, e_e the distance of the outside extended fibre from the neutral axis, e_p the distance of the outside compressed fibre from the neutral axis. In the present case the calculation gave 810 kilogrammes for the strain in tension (11,500 lbs. per square inch), and 850 kilogrammes for the strain in compression (11,600 lbs. per square inch), which are both well within the limit of 1,000 kilogrammes given above. In fact, with a load of 7,000 kilogrammes per wheel, the limit was not surpassed. The corresponding expression for the horizontal shearing strain at any point of the section is $\frac{Q\, S}{W\, b}$, where Q is the transverse load, S the moment about the neutral axis of the horizontal element of the section at this point, and b the breadth of that element. In the present case the calculation gave 619 kilogrammes as the maximum value for this strain (8,800 lbs. per square inch). A calculation of the resulting extensions and compressions of the material showed that these were also well within the limits of safety.

As these steel rails will remain on the track until their section becomes diminished, by wear of the head, below the safe limit, it is desirable to inquire when this will take place. For this purpose it is only necessary to calculate the strains on the section in the same way as before, assuming a certain portion of the top of the rail to be removed. In the present case it is found that it is not until a thickness of 10 millimètres (0·4 inch) has been worn off the head that the limit of safety will be reached for the remaining section. This thickness represents a section of 415 square millimètres: taking Rüppel's rule that the wear of steel rails is at the rate of 1 square millimètre for every 500,000 tonnes passing over them, it follows that this rail should sustain the passage of about 207,000,000 tonnes; and as the number of tonnes passing yearly may be taken as equal to four thousand two hundred trains, each weighing 275 tonnes, the probable duration of the rail is no less than one hundred and seventy-nine years. This figure is correct according to Rüppel's statement, given in the 'Deutsche Bauzeitung,' 1877, p. 198.

The conditions as to strength laid down in the specification for these rails were as follows: (1) the rail, when placed on bearings 1 mètre apart (3 feet 3⅜ inches), must bear a load of 16,500 kilogrammes (16¼ tons) without permanent set; (2) it must bear without breaking the blow of a weight of 900 kilogrammes (1,984 lbs.), falling from a height of 4½ mètres (14 feet 9 inches); (3) it must be bent to a permanent set of 65 millimètres between

bearings 1 mètre apart (or $6\frac{1}{2}$ per cent.), without showing any cracks or sign of damage; (4) it must stand being bent sideways in a rail-press to a set of 3 millimètres per mètre (0·3 per cent.), and must then be thrown from a height of 3 mètres (9 feet 10 inches) without signs of damage. The rails as manufactured have borne these tests with satisfactory results.

W. R. B.

Machine for Bending Rails. By E. SCHRABETZ.

(Wochenschrift des Oest. Ingenieur- und Architekten-Vereines, vol. ii., p. 215.)

The extended use of steel rails has necessitated a practical mode of bending them accurately for sharp curves, and this machine has been found to answer in numerous cases since 1873.

Six rails are laid on a platform, alongside each other, the first of the six being the one to be bent, while the five others serve as a fulcrum or foundation for the work. First, both ends of all the rails are fastened together by a U-shaped clip, which passes over the outside of the sixth rail, and has a lug cast on its inner edge which fits into the bolt-hole of the rail and thus prevents its slipping. The two branches of the U are then screwed together behind the first rail by a bolt. The ends of all the rails being thus rigidly connected, lateral slipping is avoided by a number of small chocks which fit into the flanges of the rails and are placed between them, each chock having an eye through which a bar can be passed for convenience of inserting or extracting it. At a distance of about 3 feet from either end, a small machine, resembling, and constructed on the same principle as, a bottle-jack, is then inserted horizontally between the fifth rail and the one to be bent. It is clear that when the bottle-jacks are turned by a forged hooked lever, specially made for the purpose, their heads will force the outer rail out, and as its ends are secured they will bend it to a curve.

A trial is necessary to determine what amount of permanent set is given to each description of rail for a certain number of turns of the bottle-jack; but this being once ascertained, it is easy to tabulate the number of turns required for each different curve, or in other words, to determine the number of times, for each curve, that the lever must be inserted into the ratchet. And this is all the workmen have to know. They receive a list in which is stated, for instance, that for a radius of 20 chains the lever must be inserted one hundred and twenty times, for one of 10 chains three hundred, &c., and thus they can carry out the work in an accurate manner.

As soon as the first rail is bent, another is drawn up from behind, and the first of those remaining is again bent; the operation of removing the U clips is simple, and the bending

apparatus falls out the moment a catch is lifted and the ratchet is turned the reverse way by a stroke of the lever. The Author asserts that two men can bend seventy to eighty rails per day of eleven hours with this machine, while the ordinary rolling machine requires six men and only bends fifty to sixty rails. The machine can also be adapted to straighten rails.

E. D'A.

Goods Tank Locomotive for Working on Heavy Lines.

By F. J. Blancquaert.

(Annales de l'Association des Ingénieurs sortis des Écoles spéciales de Gand, 1876–77, p. 49.)

The Author compares this locomotive—constructed on the Belpaire system, with eight coupled wheels, 41¼ inches in diameter, weighing, in full working order, 52 tons, or, on an average, 48 tons —with the engine, weighing 36 tons, or with tender 56 tons, employed on similar service on the Luxembourg line, having six coupled wheels 51¼ inches in diameter. Both engines work with a pressure of nine atmospheres in the boiler. Cutting off at 64 per cent. of the stroke, the average effective pressure in the cylinder, in each case, is, by Welkner's formula, 6·30 atmospheres. The resistance of the Belpaire engine is taken at 47½ lbs. per ton, equal to the known resistance of Engerth engines, and that of the Luxembourg engine at 22½ lbs. per ton of engine and tender together. Their respective capacities for drawing train-loads on an incline of 15 per 1,000, or 1 in 66⅔, are calculated from these data; for which purpose the train-resistance, at 24 miles per hour, is taken at 6 lbs. per ton. The Author here introduces the unit of gross weight, 5 tons: a wagon carrying a load of 10 tons is reckoned as three units.

The results of the calculation are, that the net train-weights which the engines are capable of drawing are as 10 to 9 respectively for the Belpaire and the Luxembourg; that the net adhesion-weights are as 6 to 5; and that the train-weight which the Belpaire engine is capable of drawing up the incline 1 in 66⅔ is 66 units, or twenty-two wagons carrying 10 tons each. This result of calculation is confirmed by the experiments of M. Masui with the engine, on various gradients. The Author gives reasons for adopting a lower co-efficient of resistance for the Belpaire engine than that of the Engerth engine.

The heating surfaces of the engines are compared, and they show that, in respect of boiler capacity also, the Belpaire engine is more powerful than the Luxembourg engine: the total surfaces are, respectively, 1,478 square feet and 1,320 square feet.

D. K. C.

On Interchangeable Parts and Reserve Couplings for Railway Drawgear. By C. Steinhaus.

(Organ für die Fortschritte des Eisenbahnwesens, vol. xiv., p. 177.)

The Author remarks that parts of a machine which are exposed to violent strains both of extension and compression are always liable to fracture; and that attempts to get over this by strengthening some particular part are generally failures, as the weakness is then transferred to some other part, often more difficult to repair. This is provided for in ordinary machines by making such parts interchangeable, and keeping them in stock, so that when a fracture occurs the part can be replaced at once and without difficulty. As parts of the drawgear of railway vehicles are in this condition, it is desirable that the same plan should be adopted with them, and that a small stock of such parts should be kept in each train to replace broken ones. A great saving would thus be effected, as the repairs themselves would cost less, and the delay and expense involved in unloading the vehicle, taking it to the repairing shops, &c., would be got rid of.

Observation shows that the most common points of fracture are the curved part of the drawhook, and the junction of the two drawbars under the vehicle. This junction is usually effected by some kind of double wrought-iron socket, into which the ends of the two drawbars fit and are secured by cotters. This has the disadvantage of weakening the section of the drawbar, which is apt to break at that point. If the socket is tapped with a right and left hand thread and the drawbars are screwed into these, the process of changing after a fracture is very awkward. On the Author's system, the end of each drawbar is screwed, and carries a square nut having a gudgeon at each side. The union is effected by a couple of short links which are slipped over these gudgeons and secured by split-pins. Their joint section is slightly less than that of the bar, so as to insure fracture occurring in the links, and these being interchangeable can be replaced from stock in a moment. This system is found to cost somewhat less in manufacture than the ordinary sockets.

In case of the fracture taking place at the drawhook, the wagon under the present system has generally to be taken to the shops; the broken hook is then cut off from the drawbar and a new one welded on. This is a matter of considerable time and expense, and has the additional disadvantage that the fresh weld is liable to make a weak place in the drawbar. On the Author's system, the drawbar terminates not in a hook but in a double eye, through which passes a plain turned pin, having a loose collar at each extremity secured by split-pins. The drawhook is made in a separate piece, and is threaded on this pin, hanging in the centre between the jaws of the double eye, but having a projection which catches on these jaws and prevents the hook falling too low. On the same pin, but

outside the double eye, are threaded two links (exactly similar to those used for uniting the drawbars), the other ends of which catch hold of the gudgeons of a coupling-nut working in an ordinary coupling-screw. On the other end of the coupling-screw is a similar nut, the gudgeons of which rest in the eyes of an ordinary shackle. When two vehicles have to be coupled up, the shackle of each is hung over the hook of the other, the wide space between the links allowing ample room for this: the upper coupling-screw is tightened by turning with a handle in the ordinary way, and the lower one is allowed to hang slack, forming a safety coupling in case the other breaks. This drawgear costs about 3*s.* more than the old form, but the excess is covered by the cheapness of repair, as a new hook can at any time be provided without delay. Again, where two vehicles are of unequal height, the hook being loose is able to follow the line of the coupling, and is thus in a better condition to resist the strain. Lastly, it is possible on this system to give a horizontal play to the couplings, which are thus enabled to accommodate themselves to the passing of the vehicles round curves. This is done by boring the holes for the drawpin, in the links, taper towards both ends, so that the links can turn slightly on the pin to follow the direction of the lateral strain. The holes in the double eye are also made somewhat slack to give freedom to the pin itself to shift slightly. The same object also may be attained by giving the drawbar, where it passes through the headstock, a certain amount of clearance, allowing lateral play.

In general, when two vehicles are to be coupled, the coupling of one of them only is used, that of the other being left to hang loose. It would obviously be an advantage if this latter could be attached in some way so as to form a reserve coupling in case of the former breaking. This has been attempted in two ways; first, by altering the construction so as to allow both shackles to hang on the opposite hooks at the same time (which is not possible with ordinary drawgear), and, secondly, by providing a separate drawhook to which the reserve coupling may be attached. The Author's drawgear is adapted for either arrangement. For the first it is only necessary to give sufficient space between the links to enable the shackle of the other coupling to be passed between them and over the drawhook. For the second, the loose drawhook is pierced with two holes instead of one; by the upper it is hung on the drawpin, while the lower is provided with a shackle-pin supporting a shackle and hanging hook to which the shackle of the other coupling can be attached. The metal of the main hook must be in this case so disposed that fracture may be sure to occur above the pinholes; and the double eye must of course be strong enough to remove all risk of fracture there. Of the two methods, the first is the cheaper, but the more awkward to apply; and, where the vehicles are closely coupled up, there is difficulty in getting the shackle of the loose coupling to pass between the drawhook and the end of the tight

coupling-screw. The second system avoids this difficulty, and also provides a reserve in case the hook itself should give way; its disadvantage is, that, being somewhat slacker, a longer time elapses after a fracture before it is brought into play, and a more violent shock is the result.

The Author considers that either system forms a stronger and more certain reserve coupling than the safety chains at present in use; while the whole cost of the latter is saved.

W. R. B.

On Kaselowsky's Improved Method of Fastening Tires.

By H. Gust.

(Organ für die Fortschritte des Eisenbahnwesens, vol. xv., p. 4.)

From a consideration of the strains to which railway tires are exposed, and the conditions under which they work in practice, the Author deduces the three following conditions as necessary on the score of safety:—

(1) The material of the tire must be such as, while possessing the greatest amount of resistance, shall be elastic enough not to be subject to sudden fracture.

(2) The amount of shrinkage given to the tire in fixing must be as small as practicable, since this necessarily produces internal strain of the material. This amount generally lies between $\frac{1}{1200}$ and $\frac{1}{1000}$ of the diameter, but in some cases it has been made as large as $\frac{1}{800}$.

(3) The body of the wheel should be made elastic, so as to lessen the strains brought upon the tire.

The first requirement can be fulfilled by proper choice of material and control of manufacture, in steel equally with iron, and by avoiding such specifications as tempt manufacturers to produce too hard a material. The second requires the abandonment of the old system of fastening by inside studs or rivets. An external system of fastening, such as the Mansel ring, is far superior in this respect, but has been found deficient in power to resist lateral shifting of the tire, and is also expensive and troublesome to apply. Kaselowsky's method of fastening is much simpler. A dove-tailed groove is turned in the inner face of the tire, and a similar one in the outside of the skeleton, so that, when the tire is slipped on, the two come opposite to each other and form a channel of dowel-shaped section going all round the wheel. Into this channel is run some easily fusible metal (by preference pure zinc), which, on cooling, makes a firm connection between the tire and wheel. In carrying out the operation the tire is only slightly heated, a shrinkage of $\frac{1}{1200}$ being found ample, and is then brought over the skeleton, which is laid in a horizontal position, and forced upon it. The zinc is then immediately run in through holes cast

in the skeleton, if of cast metal, or drilled in other cases; thus the zinc is at once prevented from cooling while being run in, and is compressed, and thus rendered much stronger, by the subsequent contraction of the tire. That this mode of fastening, in addition to its simplicity and cheapness, offers full security, both against sideways shifting and in case of breakage of the tire, has been proved by experiments made in the central workshops at Frankfort. With the first object, several wheels, having tires fixed with various amounts of shrinkage, were tested by a falling weight of 409 lbs., the wheel being laid horizontal, and the blow made to fall entirely on the tire, while the adjacent part of the skeleton was well supported and fixed. After each blow the wheel was turned through $\frac{1}{9}$ of its circumference. The results were as follows:—

Experiment 1. Zinc-fastened tire, shrinkage $\frac{1}{2000}$. The tire stood nine blows from a height of 9 feet 10 inches without injury, and then eighteen blows from 11½ feet, when, the tire being driven off, it was found that the zinc had not run the whole way round.

Experiment 2. Similar wheel and tire, but fastened with nine internal studs; shrinkage $\frac{1}{1000}$. The second blow sheared one of the studs, and by the ninth blow the whole of them were sheared, and the tire shifted almost off the skeleton.

Experiment 3. Zinc-fastened tire, shrinkage $\frac{1}{1000}$. After the fourteenth blow (from 11½ feet) a shifting to the extent of $\frac{1}{50}$ inch was produced, and by seventy-nine blows the tire was driven off the skeleton, the zinc ring being sheared all round.

Experiment 4. Zinc-fastened tire, shrinkage $\frac{1}{2000}$. Shifting was just visible at the eighteenth blow (from 11½ feet); at the thirty-seventh blow the tire broke across, the fastening being still good.

Experiment 5. Shrinkage $\frac{1}{1000}$, tire fastened with nine studs ¾ inch in diameter. The second blow from 9 feet 10 inches high sheared one stud, and by the ninth the whole of the studs were sheared and the tire shifted 1 inch.

To test the security of the fastening in case of breakage, a pair of wheels were fitted with zinc-fastened tires only 1 inch thick, and having a shrinkage of $\frac{1}{500}$. The tires were then cracked across, the first in one place, the second in two. They were placed under a loaded goods wagon, and run backwards and forwards; next made to jump a number of times over a crowbar laid on the line, and over a series of wooden blocks 1¼ inch to 4 inches high, by which the wagon was at last thrown off the line. The tires were then cracked in several more places and again subjected to similar usage, but the fastening still remained secure. These experiments and the fact that a cracked tire was worked for six weeks on the Berlin and Hamburg railway with brake action, sufficiently prove that this source of danger is entirely removed by the Kaselowsky fastening.

The cost of turning, shrinking on, and fastening the tires, is about the same (16*s.*) under both systems; to this must be added the cost

of new wheels, the cost of turning the groove in the skeleton, and cutting the air-holes, which is about 3*s*. This of course will not be required when tires are changed merely. The getting off the tires is more difficult with Kaselowsky's fastening, but, on the other hand, the zinc can be used over again. For locomotive driving wheels it might be feared that there would not be sufficient connection between tire and skeleton to prevent the latter from slipping round on the former; the "runners" of zinc, however, left in the skeleton, tend to prevent this, and at different points of the circumference the angles of the dovetail need not be taken out for a short distance, so as to form stops to prevent any possible turning of the zinc ring.

W. R. B.

On the Speed of Railway Trains as influencing their Safety.

By Dr. H. Scheffler, Engineer of the Brunswick Railway.

(Organ für die Fortschritte des Eisenbahnwesens, vol. xiv., p. 144.)

From statistics of accidents furnished by the railways of Brunswick for the years 1869–72, the Author has compiled tables indicating the influence which the speed of trains has on the number of accidents. In Table No. 1, the total number of accidents is given for each year, for the three classes of express, ordinary, and goods trains. These are then subdivided under the three heads of (1) defective condition of way or rolling stock, (2) wrong setting of points, (3) other causes. A selection is then made of the accidents in which the element of speed may be expected to show its influence, and these are divided under the heads, (1) fracture of couplings, springs or other parts of rolling stock, (2) derailment at points or crossings, (3) derailment on the open road. In Table No. 2 the same statistics are repeated, but instead of the actual number of accidents, the proportionate number per million of train miles is given for each case. In Table No. 3 the average yearly number of accidents (being the mean of the four years) is given for each class of trains; and in Table No. 4 is given the reduction of this average number to the number per million of "axle miles," where the total number of axle miles is the number of train miles multiplied by the average number of axles in a train, which is taken at eighteen for express, twenty-one for ordinary, and seventy for goods trains.

On the first glance at Table No. 3, it would appear that higher speed is an important element on the side of safety, the proportion of accidents being, for express trains 5·75, ordinary 12·75, goods 23·25. There is a widely spread impression that this is really the fact; but it is completely disproved by Table No. 4, which gives the proportion of accidents per million of axle miles as 6·81 for express, 6·11 for ordinary, and only 2·60 for goods

trains. Under some of the special heads, as derailment, the difference is still larger. As the speed of passenger trains is nearly double that of goods trains, the Author estimates that the number of accidents, other things being equal, may be taken to vary as the square of the speed. But besides the simple number, account should be taken of the "intensity" of accidents, *i.e.* the amount of damage to life and property they inflict: and as this will vary at least in proportion to the speed, the final result is that the danger to any train may be considered to vary as the cube of the speed at which it is travelling.

Another set of tables is given showing similar figures, as far as they can be obtained, from the statistics of the whole system of German railways (excluding Bavaria) for the year 1876; also the train miles for the year 1874, those for 1876 being not yet published; and the approximate result thus obtained agrees closely with that derived from the Brunswick railways, showing the proportion of accidents from derailments and collisions to be nearly twice as great with passenger as with goods trains, when the larger number of the latter is taken into account.

W. R. B.

The Block System,[1] *and Apparatus for Working it.*

By M. Sartiaux.

(Annales des Ponts et Chaussées, 5th series, vol. xiv., p. 329, 1 pl.)

Official records show that in France, in the time of the Messageries, one traveller was killed in every 355,000 who journeyed, and one was injured in every 30,000; while for the 1,781,403,687 travellers carried by French railways between Sept. 5, 1835, and Dec. 31, 1875, the corresponding ratios were one in 5,178,490 and one in 580,450 respectively. It will thus be seen that the risk is much less on railways than it was by the old methods of transport. Moreover, the number of accidents in proportion to the number of passengers has notably diminished since the first introduction of railways. For example, taking the case of a person travelling regularly by railway in France for ten hours every day, at the rate of 31¼ miles per hour, his chance of being killed would have been as follows:—

Between	1835	and	1855	one	chance in	321	years.
„	1855	„	1875	„	„ „	1,014	„
„	1872	„	1875	„	„ „	7,439	„

The diminution in the proportion of accidents is due partly to improvements in the rolling stock, permanent way, and brakes, and partly to improvements in the methods of signalling, and

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[1] *Vide* "Cornhill Magazine," March 1869.

to the block system, which substituted intervals of distance for intervals of time between the trains. The absolute block system, which is mostly in use in England, Germany, Belgium, and Holland, and consists in dividing the line into sections, and forbids a train entering a section till the preceding train has quitted it, ensures the greatest amount of safety; but it has been objected to as delaying traffic, and as preventing a train whose engine has broken down from being helped on by the succeeding train. The permissive block system has been accordingly proposed as a remedy, which allows the succeeding train to enter a blocked section slowly, and with the train so under control that it can be stopped within a short distance.

Various kinds of apparatus have been designed for carrying out the block system. The simplest form of apparatus consists of a telegraph between the stations; but this is only suitable for lines with little traffic, and where the stations are only about 3 or 4 miles apart. It is employed on a portion of the Dutch railways where the block system was enforced in 1875. The first apparatus designed by Mr. Cooke, the originator of the block system, was complicated, and was soon abandoned, but an apparatus of a more practical form was introduced by M. Regnault in 1847, and a similar one by Mr. E. Clarke about the same time, and several other instruments have been designed since. These may be classed under two heads. (1) Those in which the electrical signals are distinct from the signals displayed, to which the Tyer and Regnault instruments belong. (2) Those in which the electrical signals are connected with the semaphore signals, to which the Siemens and Halske, and also the Lartigue, Tesse, and Prudhomme instruments belong.

The Tyer apparatus consists of a receiving instrument containing two needles of different colours, one for each line, which according as they are moved to the right or left indicate that the line is clear or not. With this apparatus five separate operations have to be performed. The man at the signal station A signals to station B that a train is entering the section between A and B; the man at station B makes his apparatus and the one at A indicate "line blocked"; the man at A puts his semaphore signal at danger as soon as the train passes him; the man at B makes the signal of "line clear" at his and A's dial when the train has passed his station; lastly, the man at A lowers his semaphore signal.

Besides the inconvenience of requiring the signalman to repeat on the semaphore the signal transmitted him by telegraph, the Tyer apparatus is rather easily put out of adjustment by a shake or by atmospheric electrical disturbance; it necessitates the constant presence of a signalman at each signal station, and the man at A can signal "line clear," without the man at B being able to interfere. It is, however, notwithstanding these drawbacks, in use on several English lines, and on lines in France for a distance of 334 miles.

M. Regnault's improved apparatus is similar in many respects

to the Tyer apparatus. It has two needles, one bearing the name of indicator, and the other repeater, which are vertical when the line is clear, and inclined when a train is in the section. There is a dial on both sides of the receiving instrument, so that the needle can be seen both inside and outside the signal box. When a train enters the section A B, and the signalman at A makes the electrical current deflect the needle at B, at the same time sounding a bell at B, the needle in deflecting touches a nob, which causes a current to be sent back to A, deflecting the repeating needle at A, thus informing the man at A that his signal has reached B. It rests with the man at B, as soon as the train has passed his box, to replace his indicator needle in a vertical position, which causes the repeater needle at A to return to the vertical, and till this has been done the man at A cannot send another signal. This apparatus has consequently the advantage of dispensing with the necessity for the constant attendance of the signalman, and of preventing a signalman suppressing a signal once sent. The only objection to the apparatus is that it does not connect the signal transmitted with the external signal.

The apparatus of Messrs. Siemens and Halske connects the signal transmitted to the signal box with the one exhibited outside. When the blocking signal is transmitted from a station to the station in front the signal of the station behind is simultaneously placed back to "line clear," and it is impossible for a signalman to replace his own signal at "line clear." This, however, necessitates the use of a double apparatus where trains are shunted, as the only means with a single apparatus of unblocking a section is by blocking the section in front, which would forbid the passage of the train arranged to pass the shunted one. The defects of the apparatus are that its mechanism is complicated and delicate, and that it furnishes no indication to the signalman that his signal has reached its destination. This apparatus is in use on several German railways, and also in Belgium.

The apparatus of MM. Lartigue, Tesse, and Prudhomme,[1] connects the electrical with the semaphore signal. When a train enters the section A B, by a single turn of the handle of the instrument at A the danger signal is raised at A, a bell is rung at B and a red disc also displayed indicating that a train has entered the section; and a return current gives a similar indication at A that the signal has reached B. When the train reaches B the man at B has to perform the same operation as previously done at A, and by turning the handle of a second apparatus he unblocks A, and receives back the indication that his signal has reached A.

Like the Siemens apparatus, the apparatus of MM. Lartigue, Tesse, and Prudhomme prevents a signalman from unblocking his own station; and in addition to the improvement of returning a record of the arrival of a signal, it possesses the advantages of

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[1] *Vide* "Annales des Ponts et Chaussées," 5th series, vol. xiv., p. 197.

strength, durability, easy maintenance, and a simpler method of application of the electrical force, and moreover requires less skill and attendance on the part of the signalman. The cost of the instruments of MM. Tyer and Regnault, and the expenses of keeping them in repair, are less than for the other two; but taking into account the wages of the experienced signalmen required for working the Tyer instruments, and even to some extent for the Regnault and Siemens instruments, it appears that the Lartigue apparatus is, on the whole, the most economical, as well as the best in other respects.

L. V. H.

On a Safety Lock for Switch and Signal Connections.

By Inspector Beemelmans.

(Organ für die Fortschritte des Eisenbahnwesens, vol. xiv., p. 273.)

Under the present system of connecting points with signals, both worked from a central signal cabin, it often occurs that points have to be moved which are so far from the cabin that the operator is unable to see whether the switches are close home to the rails or not. It is most important there should be no mistake as to this, since if the points are a little open, especially where they are facing points, there is great danger of their throwing a train off the rails. Various devices have been used for ensuring the points being brought home, and for fixing them when home, of which the best known is perhaps Saxby and Farmer's No. 2 Locking Bar, which is effectual but cumbersome and costly. The present arrangement, which is much simpler, was designed by Messrs. Schnabel and Herming, of Bruchsal, for the German State railways, and has been applied with success to work a pair of points at the Strassburg station, 273½ yards from the signal cabin.

The principle of the apparatus is as follows:—At the centre of the connecting-rod, between the two switches, is a spindle, on which is mounted a bell crank lever, having three arms. One of these arms hangs downwards, and is connected by a joint to the point-rod leading to the apparatus; the other two are at right angles to this on either side, and carry each a small roller at its extremity. Immediately below each an angle plate is fixed to the ground, having one table horizontal and the other inclined downwards. Between these two angle plates is an opening about equal to the travel of the points. When the points are home in one position, the corresponding horizontal arm bears against the inclined table of its angle plate. If it is desired to shift the points to the other position, the apparatus in the signal cabin is worked, which produces a pull or push, as the case may be, on the end of the vertical arm. The first effect is merely to turn the bell crank lever on its spindle until the horizontal arm rises free from the inclined table. It then continues turning until the other horizontal arm comes

down on the horizontal table of its angle plate. It can now turn no further, and the next effect of the pull or push is, therefore, to move the points across into the other position. During this motion the horizontal arm moves along on the horizontal table; and when the points are just home, but not before, it slips over the edge on to the inclined table. The lever is now free to turn on its spindle again, and thus gives a still further motion to the lever of the apparatus, which is required before that lever can reach its notch at the further side of its quadrant. It will thus be seen that it is impossible to get the lever into its notch unless the points are home, and when once the lever is in its notch the points are firmly locked, as the horizontal arm, bearing against the inclined table, prevents the points from moving backwards. The apparatus is enclosed in an iron casing, and cannot be affected by the passage of the trains.

W. R. B.

Endless-rope Tramways at San Francisco. By M. LAVOINNE.

(Annales des Ponts et Chaussées, 5th series, vol. xiv., p. 465, 2 pl.)

The town of San Francisco is well supplied with horse tramways, but the inclines of some of the principal thoroughfares are too steep for this method of working, and these streets, situated in the busiest portion of the town, were in danger of losing trade in consequence of their inaccessibility. A method of traction by an endless rope was accordingly devised, in such a manner as not to interfere with the ordinary traffic. A tramway on this system was laid first along Clay Street, from the point where it is crossed by Kearney Street; from this point it rises, with inclines of from 1 in 8·54 to 1 in 6·17, to a height of 307 feet, and then falls with gentler gradients to Leavenworth Street. It is between Kearney Street and Leavenworth Street that the rope tramway was first applied. The distance is about 51 chains, and in this distance Clay Street is crossed by five other streets, which crossing involves the cessation of continuity in the inclines of Clay Street; as these are broken up by five levels by which the traffic of the transverse streets is carried across Clay Street. The rope works in two cylindrical underground passages, one under each line of rails. The passages are lined with wooden staves, and have an internal diameter of 2 feet 3½ inches, and their axes are about 1 foot 9½ inches below the surface; they are fitted with rollers for guiding the rope, and to prevent its touching the sides where the inclination alters. There is a groove about 1 inch wide near the top of each tube, through which the connection between the car and the rope is effected. The rope, which is 1 inch in diameter, consists of 114 strands of tempered steel, and goes from the up to the down line round a horizontal pulley, 7 feet 10 inches in diameter, at the bottom of the incline, and after passing over

two pulleys at the top, it is wound twice (*sic* in original) round a grooved pulley, 8 feet 10 inches in diameter, which is turned by a 30-HP. high-pressure steam engine, imparting to the rope a rate of motion of 4 miles an hour. The ordinary tram cars are attached to a dummy running on the incline. The mechanism for catching hold of the rope consists of a steel piece in the shape of the letter L, the upper portion of which slides in the groove of the tube, and is fastened to the dummy, whilst the lower part carries two jaws, one fixed and the other movable, so that by turning a screw on the dummy connected with the movable jaw the dummy can be attached to or released from the rope at pleasure. The man regulating the motion is stationed on the dummy, which is fitted with a brake, and has seats round the outside for nine passengers. The car attached to it carries fourteen passengers. The total cost of the work was about £20,000.

A similar tramway has been since laid down along Sutter Street, which has a maximum inclination of 1 in 14·3, and only rises 164 feet above the street it joins.

The passages for the rope are made with arched cast-iron sides, instead of with concrete, which was used under Clay Street, resting on timber sills. Four grooved wheels, two above and two below, between which the rope runs, which can be brought close together or separated by moving a lever on the dummy, serve for connecting the dummy to the rope and disconnecting it, instead of the arrangement of jaws which caused considerable wear on the rope. The dummy changes line by means of points and crossings at each end of the incline, which enables the shunting to be performed more rapidly than with the turntables laid down at Clay Street. The dummy is detached from the car on approaching the points, and changes line, whilst the car remains on the same line, and continues its journey on the tramway of the adjoining street; and there is an arrangement by which the wheels of both dummy and car, passing alternately over the points, shift them after passing to be ready for the succeeding vehicle.

A third tramway has recently been completed along California Street; and another is in course of construction along Geary Street, where a cast-iron tube forms the passage for the rope, and the timber lining adopted in the first two cases has been dispensed with.

L. V. H.

On the Working by Steam Power of a Tramway between Cassel and Wilhelmshöhe. By E. Heusinger von Waldegg.

(Organ für die Fortschritte des Eisenbahnwesens, vol. xiv., p. 302.)

The advantages of using steam as the motive power on tramways (a question which the Author considers to be now pressing for solution) is shown by the fact that the cost of transport by railways is only one-fifth and by horse tramways only one-half of that on a paved road. On the American tramways it has been

found that six steam cars will do the work of eleven horse cars, and in Copenhagen the use of Merryweather's engine has effected a saving of 40 per cent. on the cost of working.

The tramway at Cassel was constructed from the designs of Mr. P. P. Gordon, and the contract for working it was taken by Messrs. Jay and Co. of London. The line, which is about 3½ miles long, is laid with steel rails of 36 lbs. per yard, fastened down by hooked spikes on longitudinals of fir, 5 inches by 6 inches, which are united by iron knees to cross sleepers, also of fir. It has a gradient of 1 in 16·6 upon a curve of only 164 feet radius. There are ten stopping places on the line, with a passing place and turn-out at each. At one place there is a level crossing over a railway, which is met by letting the railway rails cut the tramway rails at a slightly lower level, the difference being the height of the tram-wheel flanges, so that the tramway runs across the railway rails on their flanges. The motive power first tried was compressed air, but this was by no means successful; and steam engines by Messrs. Merryweather and Sons were substituted. These are four-coupled engines of locomotive type, but with the fire door at the side instead of the end of the boiler, where also is the place of the engineer. The weight of the engine with 2 tons water is about 9 tons. The consumption of fuel is 88 lbs. of coke for a complete journey of about 6·6 miles. Firing takes place only at the terminus, so that there is no smoke on the journey; neither is there any escape of steam, of which the greater part is passed into a hot well and then into a tubular condenser, and the remainder into the chimney (which is inclosed within the condenser) to increase the draught. It is an objection to this engine that it has no elastic draw and buffing gear, so that there are unpleasant shocks in starting and stopping. Also for the small speed permitted (7½ miles per hour) outside instead of inside cylinders might have been employed, with great advantage in simplification and economy. The engine has however taken two fully loaded cars up the gradient of 1 in 16·6 without difficulty. Only two engines were at first in work, and these in twenty-two days of July made 302 trips, carried 34,000 passengers, and earned about £430. There have been no stoppages or accidents, and no cases of alarm to horses. This successful result is considered to be in great measure due to the locomotive being separate from the car. The combined car and engine cannot in general be turned round at each terminus, owing to its unwieldiness and the impossibility of using turn-tables; hence it has to run backwards during one-half of the trip, which is prejudicial to safety. The greater power of the engines here used had also much to do with their success; they were of 20 HP., having 7½-inch cylinders, while the Merryweather engines at Paris and Copenhagen are 8 HP. only, having 4-inch cylinders.

The Author considers that experience enough has been gained to allow not only of the relaxation of the legal restrictions to the use of steam power on tramways, and to sweep away

horse traction altogether, but also of a large extension of the system for light connecting lines of railway to be laid at small cost on common roads; the speed on these lines not to exceed 12 miles per hour, and the engines to be such as will require only a single attendant. The track should be of the best description with steel rails and iron sleepers; such a track can be laid complete at a cost per mile of £1,200 for material, and £300 for laying. Rolling stock, such as used at Cassel, can be bought at the following prices: Locomotive, £500; covered car, £200; open car, £125; and open goods wagon, £75.

W. R. B.

Wire Rope Conveyance. By M. Korting.

(Annales industrielles, December 9, 1877, col. 742.)

A system of aërial transit on suspended wire ropes, designed by Messrs. Bleichert and Otto, of Leipzig, has been established to connect the gasworks at Hanover with the neighbouring coal station on the Hanover-Altenbeck railway, for the supply of coal to the works. The line crosses the Limmerstrasse and the river Ihme, and is about 625 yards in length. There are two iron-wire ropes, placed 5 feet 10 inches apart, and employed respectively for the carriage of loaded and of empty wagons. They cross the Limmerstrasse at a height of 23½ feet, and the river at about 30 feet. The cables are respectively 1·12 inch and 1 inch in diameter, and are constructed of wire of 4 millimètres, about ⅛ inch, in diameter. They are supported on pulleys at intervals of 24 yards, except in crossing the river, on a span of 57 yards. Resting on pulleys, they are free to expand or contract. They are kept taut by weights of 5 tons and 4 tons respectively.

The wagons are drawn by means of a $\frac{9}{16}$-inch endless wire rope, supported on rollers at intervals of 60 yards, and driven by a six-horse steam engine at a speed of 3 miles per hour. The wagons are constructed of sheet-iron, and are capable of holding 3 hectolitres, or 106 cubic feet, of coal; they are suspended from the carrying ropes on two grooved wheels, one in advance of the other, between which the attachment of the wagon is made. The bodies of the wagons are swivelled, so that they may be easily emptied. They follow each other at intervals of about 60 yards. Allowing for delays, the quantity of coal carried at no time exceeds 180 tons per day of ten hours, and is frequently less, the average delivery being only 135 tons. The working charges are:—

	£.	s.	d.
Seventeen men at 2*s.* 6*d.*	2	2	6
One carpenter.	0	3	5
Coal for the engine	0	6	4
Oil, waste, &c.	0	0	5
Per day	2	12	8

being at the rate of 4·67*d.* per ton of coal conveyed. The total first cost of the system amounted to £3,580, and the charge for interest, depreciation, and 15 per cent. for maintenance, is reckoned at 5·13*d.* per ton, making a total charge of 9·8*d.* per ton, the former cost being 1*s.* per ton.

D. K. C.

On the Mineral Wealth of the Province of Santander.

By A. Piquet.

(Compte rendu de la Société des Ingénieurs civils, 1877, p. 259.)

In the sixteenth and seventeenth centuries the province of Santander was known to contain mines of gold, silver, lead, and copper, the localities of which are mentioned in the archives of Simancas; but these records do not give any just idea of the present importance of the mineral wealth of the district, since iron mines are rarely mentioned in them, and deposits of calamine are not noticed at all, as the value of this mineral was not known.

The greater part of the surface of the province consists of strata of cretaceous and triassic age, and there are smaller areas of the carboniferous and jurassic formations, and patches of Devonian and nummulitic beds, of alluvial deposits, and of granite and other plutonic rocks. A geological map of the district accompanies the Paper.

The cretaceous rocks are the richest in workable ores, thirty concessions of zinc and twenty-two of iron ore having been worked in them in 1872; and next in richness follow the carboniferous, the triassic, and the jurassic formations.

The deposits of calamine, in the cretaceous beds, extend from the extreme west of the province to beyond Santander. They occur generally in the neighbourhood of beds of dolomite, and are of irregular form, and limited in depth, but in most cases follow the direction of the stratification. The occasional occurrence in them of elephant and rhinoceros teeth, impregnated into calamine, indicates that the deposition of this mineral must have occurred in, or continued down to, the miocene period. The ores that they contain are hydrated and anhydrous carbonate of zinc, silicate of zinc, and blende, more or less pure, and in some cases mixed with oxides of iron and manganese. Galena and carbonate and sulphate of lead are also found in them occasionally. The principal companies working them are the Royal Asturian Company and the Mining and Foundry Company of Santander and Quiros. The mines of the latter company produce annually about 10,000 tons of raw calamine. Particulars are given of the characters of the chief deposits worked by the company, and of the cost of dressing and calcining the ore. The mines of the Asturian Company yielded in 1872, 45,500 tons of calamine. The workable

deposits of iron ore in the cretaceous formation consist of masses of anhydrous and hydrated peroxide; the annual output exceeds 40,000 tons, and might be much increased.

The zinc ores in the rocks of carboniferous age occur in veins, and consist of calamine associated frequently with blende, galena, and carbonate of lead, and sometimes with cinnabar. Many of the mines are situated at a great elevation, in the higher parts of the Peñas de Europa, and can be worked only in summer. Their total annual output is between 8,000 and 9,000 tons.

The only important deposit of ore known to occur in the trias is that at Mercadal, near Torrelavega. This mine produced, in the five years ending with 1872, 11,400 tons of calcined calamine; but it is now nearly worked out. Full details are given of the mode of working the deposit, and of the system of dressing and calcining the ore, which consists of calamine mixed with blende, and in parts with galena. The description is illustrated by plans of the general surface works of the mine, and of the arrangement of the dressing machines, and by drawings of the kilns and reverberatory furnaces employed for calcining.

An important deposit of iron ore has been discovered at the junction of the triassic and jurassic formations, in the circuit of Torrelavega. The ore is a pure hydrated peroxide, containing 56 to 59 per cent. of iron, and about 3 per cent. of manganese.

The principal mineral deposit in the jurassic formation of the province is one of copper pyrites, yielding 11 per cent of the metal. 2,000 tons of this were obtained in 1872.

Catalan forges were in operation in thirty-four localities in the district in 1840, but have now completely disappeared.

In addition to metalliferous minerals, the province contains deposits of rock-salt, lignite, bituminous schists and grits, peat, and valuable marbles and other building materials, as well as a variety of warm and mineral springs.

The Author, in conclusion, gives some particulars of the roads, railways, and ports of the province, and discusses the additional facilities for transport that are required; explains the mode of calculating the value of the different ores, according to their richness and the market price of the metal at the time; and states some facts as to population and climate.

W. H.

On the Treatment of Oxidised Ores of Nickel. By J. Garnier.

(Compte rendu de la Société des Ingénieurs civils, 1877, p. 441).

The ores of nickel found in New Caledonia are hydrated silicates of nickel and magnesium, of a peculiar green colour, and occurring

as layers, strings, and nodules, imbedded in serpentine. The following are analyses of three samples:—

	(1)	(2)	(3)
	Per cent.	Per cent.	Per cent.
Protoxide of nickel	3·50	8·50	18·50
Protoxide of iron	5·18	2·50	3·50
Lime	2·20	17·28	2·65
Magnesia	26·65		15·75
Silica and other insoluble matter	41·75	57·50	50·00
Water	21·25	14·50	10·00
	100·53	100·28	100·40
Nickel	2·75	6·60	14·62
Iron	4·03	1·94	2·45

It is probable that similar ores exist, associated with serpentines and diorites, in other parts of the world, though they have not hitherto been noticed, since from their want of lustre, and their low density when not exceptionally rich, they may readily have been overlooked.

The ore is screened and hand-picked; as, on account of its low density and friable character, it cannot be concentrated by washing, and the finer portions are then crushed and agglomerated.

Two methods of obtaining the metal from it are in use. The first is that of producing a carburet of iron, containing nickel, or even a nearly pure carburet of nickel, by smelting the ore in a cupola or small blast furnace, as cast iron is ordinarily made, and subsequently removing the iron by cupellation. The second, which is sometimes preferable in the case of poor ores, is fusion with reducing agents and materials containing sulphur or sulphur and arsenic, such as iron pyrites or sulphate of lime. This yields a sulphuret of nickel and iron, similar in composition to the sulphuretted ores of nickel that are commonly worked. By a suitable regulation of the process, a great part of the iron may be slagged off, and the nickel concentrated in the regulus, which is of the following composition:—

	Per cent.
Nickel	50 to 70
Iron	25 to 15
Sulphur	25 to 15

The subsequent treatment of this regulus is a part of the ordinary metallurgy of nickel, and need not be described.

The cupola used for obtaining the metal in the form of a carburet of nickel and iron is about 13 feet high, and is blown with cold air at a low pressure. The hearth is small, and arranged so that the metal in it shall be maintained at a high temperature. Under these conditions the nickel is readily reduced and carburetted, while a greater or less proportion of the iron passes into the slag. The carburet of nickel and iron is more fusible than ordinary cast iron. In smelting rich ores, such as that of which

the composition is given in No. 3 of the above analyses, it is possible, by adjusting the amount of blast, and other conditions of working, to obtain an alloy of any degree of richness, up to a pure carburet of nickel, nearly free from iron. An ordinary composition of the alloy yielded by ore containing equal amounts of nickel and iron is—

	Per cent.
Nickel	60·90
Iron	33·35
Silicon	0·85
Carbon	3·90
	99·00

Poor ores, containing at the same time little iron, are smelted with the addition of so much oxide of iron as will render the slag fusible, and will give at the same time a yield of cast iron equal to about 15 per cent. of the weight of ore charged. The loss of nickel, which would occur in smelting these ores alone, is thus prevented.

The carburet resulting from this first fusion is refined by remelting it on the bed of a reverberatory furnace, either alone, when pure nickel is required, or together with copper to produce alloys suitable for making German silver. The oxidation of the carbon, silicon, and iron soon begins, and is aided by the addition of oxidising agents, such as oxide of copper or of manganese. The slag formed is skimmed off at intervals, samples are taken from the bath, and when the metal appears to be free from iron it is cast into ingots.

The Author has been engaged for some time in experiments on the production of useful alloys of nickel and iron, but has hitherto found great difficulty in making these of reliable quality, on account of the marked effect on the properties of the metal of small amounts of impurity.

W. H.

On the Smelting of Native Copper at Lake Superior.

By F. Kupelwieser.

(Berg- und hüttenmännische Zeitung, vol. xxxvi., p. 231.)

The materials delivered from the mine consist of masses yielding 96 to 97 per cent. of copper, dressed mineral of 80 to 85 per cent., and slimes of 30 to 40 per cent. These are smelted by the Detroit and Lake Superior Copper Smelting Company at two establishments; that at Hancock, in the mining district, has eight reverberatory smelting and refining furnaces, and three cupolas for slag smelting, while the other, at Detroit, has four refineries and two cupolas only. The refineries are of the ordinary South Wales pattern, except

that a portion of the arched roof is made movable in order to facilitate the charging of masses of copper, which are lowered on to the bed by a crane, and passages are left in the fire-bridge for the introduction of heated air in the refining process. The charge consists of 8½ to 9 net tons (of 2,000 lbs.); the largest masses, being placed below, are covered by the dressed mineral, 1 to 1½ cwt. of limestone, and 4 or 5 barrows of rich slags. The furnace is charged at 2 P.M., and fusion is complete after twelve hours' firing, the slags being drawn at 2 A.M., and at intervals up to 7 A.M., when the refining process commences, air being introduced for about one hour and a half until the copper is completely dry, when the refining slag is drawn and coal added for reducing the dissolved suboxide. The subsequent operation of poling, commencing at 8 or 9 A.M., lasts about an hour, and the ladling of the metal, when at the proper pitch, into ingots, two hours more; so that the furnace is emptied at noon, and two hours are left for examining and repairing the bed before commencing the working of the next charge at 2 P.M. The copper is cast partly into rectangular bars of 4 to 7 inches by 4 feet long, for wire-drawing, but more generally into small ingots, deeply notched on the under surface, weighing about 16 lbs. each. The yield per charge is 6·63 tons of ingot copper, and the consumption of bituminous coal is 3·62 tons in twenty-four hours. The slags, containing from 8 to 12 per cent. of copper, are smelted in Mackenzie's cupola furnace, which is of an elliptical section; the hearth measures 2 feet 3½ inches by 4 feet 2 inches, and the stack 3 feet 6 inches by 5 feet 6 inches, and 9 feet 10 inches high. The hearth is 2 feet 10 inches deep, the blast being distributed through a narrow slit in the lining, forming a continuous tuyere somewhat similar to that of the Raschette furnace. The boshes are formed by a hollow casting, 1 foot 8½ inches high, cooled with water. About 20 tons of slags are passed through the furnace in ten or twelve hours, the only flux employed being limestone to the extent of 35 or 40 per cent. of the weight of the material treated.

The smelting is effected for account of the mines, on tolls, $18 per ton of mineral and $13 per ton of slags being charged by the smelters. The cost of labour is said to be $19 per charge, and $8·60 and $10·56 per ton of ore and copper respectively. From 17,000 to 18,000 tons (of 2000 lbs.) of mineral are smelted annually.

H. B.

The Rammelsberg Mine in the Lower Harz. By F. Wimmer.

(Zeitschrift für das Berg-, Hütten- und Salinen-Wesen, vol. xxv., p. 119.)

The celebrated pyritic deposit of the Rammelsberg, near Goslar, in the Lower Harz, is remarkable not only historically as having been worked continuously for nine hundred years, but also for

the peculiar nature of the mineral, which is a mixture of ores of several different metals, so intimately combined that they cannot be separated by any mechanical process, and it therefore requires a peculiar system of metallurgical treatment for its reduction. The deposit consists of a series of irregular lenticular masses resembling a vein, but actually a bed, dipping with the stratification of the rocks (about 45°) on the east flank of the Rammelsberg, a hill about 2,000 feet above the sea-level, near the junction of the Wissenbach Upper Devonian schists with the Calceola sandstones, a lower member of the same formation; which, however, by reason of the great disturbance in the strata, are inverted in position, the lower formation being apparently below the upper one, and a still lower series, the Spirifer sandstones, which form the mass of the Rammelsberg, above both of the preceding. The longitudinal extension of the deposit, as far as it has been hitherto traced, is about 1,300 yards, and the greatest thickness, measured perpendicularly to the strike, from 48 to 65 feet; but at the point where an eastern or hanging branch—produced by an extreme contortion in the strata—joins the main deposit, this is exceptionally increased to above 100 feet. The greatest depth of the workings is about 300 yards below the outcrop. The vein material consists principally of compact mixtures of the following minerals:—

1. Galena, with zinc blende and iron pyrites; sometimes the latter and sometimes blende being the most abundant.

2. Galena with barytes in variable quantities. When the latter is in excess, the mixture is known as grey ore, or when mixed with blende, as brown ore.

3. Copper pyrites and iron pyrites in every possible proportion, with some arsenical pyrites—sometimes, but rarely, free from blende and lead ore.

The pyritic masses are chiefly found on the hanging wall and central parts of the bed, the lead ore and barytes keeping to the foot wall side.

The separation between the ore bed and the neighbouring strata is most sharply defined on the latter side; on the hanging wall the pyritic impregnations penetrate a certain distance into the rock, forming the so-called "Kupferkniest."

Besides these minerals, numerous others are known to be present, though not in recognisable quantities; as the analysis of the ores shows them to contain not only copper, lead, zinc, sulphur, barium, and arsenic, but, in addition, gold, silver, mercury, bismuth, manganese, cobalt, nickel, antimony, selenium, and iridium.

Another class of minerals of secondary origin is found in the old workings, where the pyritic waste has, by oxidation, been converted into a mixture of sulphates; and the change having also extended to the slaty rock, the whole is sometimes found to be compacted into a solid mass, which has to be worked like new ground. The mixed sulphates, principally of iron and copper, are known as copper-meal (Kupferrauch), and the compact material as

inkstone (Atramentstein); both are used in the manufacture of vitriol, alum, and similar products.

The working of the ore is effected by over-hand stoping, the whole thickness of the deposit being taken at the same time, commencing from the lower working level and rising in terraces. The main levels are driven in the rock on the hanging wall side, the ore, as it is broken in the workings, being thrown down through vertical shafts (mills) carried up, or nearly so, through the waste. The ground is now almost exclusively broken by gunpowder, the old plan of fire setting, which distinguished the Rammelsberg workings for so many centuries, and was almost exclusively used until within the last twenty years, having been nearly abandoned, owing to the increase in the price of firewood and the improvement in blasting materials, which allow of the latter being advantageously employed on ground that was formerly considered to be too hard for working by any means but fire. A certain advantage is, however, still claimed for the old method, on the ground of economising labour, as by its use ore ground may be broken upon holidays, when the men are out of the mine. The excavations where ore has been removed are principally secured by walling, stone for the purpose being obtained from a sandstone quarry near the principal drawing shaft, but at a higher level; the broken stone being first lowered by an incline to the shaft landing, whence it is sent down through the main levels to the working points. Timbering is extensively used in the shafts and levels, as the vitriolic mine water has a very beneficial effect in preserving wood from decay. The average annual production of ores of all kinds is about 30,000 tons, and the amount of filling material required from the surface is from 14,000 to 15,000 tons, or very nearly an equal volume to that of the ground removed.

The ores are broken underground into lumps of 6 or 7 lbs. weight, and when brought to the surface are subjected to a classification by hand; the waste and poor ores—which in the case of lead includes 6 per cent. and those of lower produce—being separated. The small mine stuff alone is subjected to a partial system of dressing by jigging machines, which, however, does not extend much beyond separation into sizes. The ores are delivered to the smelting works, and the vitriolic products from the old workings are sold to the copperas manufactories in the neighbourhood. In addition to these products, a certain quantity of ochre is recovered from the water, the drainage from the adit being allowed to run through pits in which the ochre is deposited.

H. B.

The Lower Harz Smelting Processes. By Herr Bräuning.

(Zeitschrift für das Berg-, Hütten- und Salinen-Wesen, vol. xxv., p. 132.)

The metallurgical treatment of the ores raised from the Rammelsberg mine is carried out at three different establishments,

namely, Oker-Hütte, about 3 miles east of the mines; Julius-Hütte, at Langelsheim, and Sophia-Hütte, near Astfeld, 4 and 6 miles respectively distant to the north-west. At the Oker works the smelting of the copper and mixed lead and copper ores is carried out in combination with the manufacture of sulphuric acid, the others being devoted to lead smelting and desilverising.

For the purposes of the smelter, the ores are divided into the following classes:—

1. Lead ores. These contain chiefly blende, iron pyrites, galena, and barytes; the proportion of lead not being less than 6, and the average from 8 to 9 per cent.

2. Mixed ores. Containing blende, pyrites, galena, copper pyrites, and barytes; the first two minerals being most abundant, and galena and barytes less in proportion than in the lead ores.

3. Ordinary copper ores. Essentially coppery pyrites, the average proportion of copper being from 7 to 8 per cent. Blende and galena are occasionally accessory constituents, but barytes is almost entirely wanting.

4. Rich copper ores. Principally copper pyrites, with some iron pyrites.

5. Kupferkniest. Slate impregnated with pyritic minerals to the extent of 25 to 40 per cent. The amount of copper varies considerably, but, on a large average, is from 4 to 5 per cent.

The whole of the ores contain gold and silver, the latter varying from 0·01 to 0·02 per cent. (6½ oz. per ton), and the former as computed indirectly from the proportion found in the test silver, from 8 to 15 grains per ton. The average composition of the ores, as determined by analysis, is as follows:—

	Sulphur.	Copper.	Lead.	Iron.	Zinc.	Manganese.	Barytes.	Other Vein Stuffs.[1]
Lead ores . .	25·00	0·55	11·79	11·86	23·86	2·18	15·97	7·48
Mixed ores . .	27·18	5·06	9·52	16·26	18·19	1·75	13·77	6·02
Rich copper ores	32·89	15·66	4·88	25·32	7·90	1·64	6·66	4·47
Ordinary copper ores . . .	41·08	7·90	2·17	34·93	3·71	1·08	0·63	7·27

Cobalt and nickel together vary from 0·04 to 0·08, and arsenic and antimony from 0·08 to 0·12 per cent.

The average annual deliveries of the different classes of ores are as follows:—

	Tons.
Lead ores	12,500
Mixed ores	3,750
Ordinary copper ores	4,200
Rich copper ores.	1,500
Kniest	1,000
	22,950

Of the above quantities about 15,000 tons are treated in the

[1] Silica, alumina, carbonate of magnesia, and carbonate of lime.

sulphuric acid works. These include the whole of the non-cupreous pyrites, ordinary copper and mixed ores, with the exception of dressed slimes, pyritic lead ores, and rich copper ores, with the exception of the very richest portions. The average quantity of sulphur is somewhat above 30 per cent., a large proportion of which is not, however, available for producing acid, the different minerals being of very unequal value in this respect. Thus no portion of the sulphur in galena can be so utilised; and copper pyrites is not much more valuable, as it produces only a very weak gas, and decrepitates to such an extent as to interfere with the draught of the roasting furnaces. Blende is somewhat more useful, the pyritic and blendy lead ores with 35 per cent. of blende and 20 per cent. of iron pyrites being found to give a workable gas in the acid chambers.

The richer ores, broken to pieces $\frac{1}{8}$ inch in the side, are treated in pyrites burners with movable grates, the column of material being only about 3 feet high, in order to prevent too great a concentration of heat, and consequent fusion of the mineral; those poorest in sulphur are reduced to $\frac{1}{4}$-inch lumps and burnt in kilns about $7\frac{1}{2}$ feet high.

The acid works, which are described in full detail, are the largest in Germany, including fourteen series of lead chambers of a total capacity of nearly 800,000 cubic feet. The production of rough acid varies with the character of the ore from 75 to 110 cwt. daily, or from 4 to 5·7 lbs. per cubic mètre of chamber. The residual sulphur in the burnt pyritic ores amounts to 6 per cent., and in the other kinds to 10 or 12 per cent.

By far the larger proportion of the acid is sold in the crude state, at a strength of 50° Beaumé (specific gravity 1·5), and is sent away in cylindrical lead tanks of $7\frac{1}{2}$ tons capacity, mounted on railway trucks. The remainder is concentrated to 66° in platinum vessels after a preliminary purification from arsenic and antimony by means of sulphuretted hydrogen.

In the metallurgical treatment proper the lead ores, mixed ores, and rich copper ores are smelted in blast furnaces, while the ordinary copper ores, after passing through the acid works, are treated by the wet extraction process, the succession of the different operations being indicated in the following sketch.

1. The lead ores are roasted in heaps until nearly desulphurised, and smelted for lead, which is desilverised by cupellation. Sometimes a portion of the roasted ore is lixiviated for the production of sulphate of zinc.

2. Mixed ores are treated similarly to the preceding; producing in addition to furnace lead a regulus containing copper. This, after concentration, is treated, together with the similar regulus obtained in smelting the rich copper ores.

3. Rich copper ores are subjected to a partial roasting fusion for 30 to 40 per cent. coarse metal, and a second fusion for concentrated (66 to 70 per cent.) regulus, the latter operation being attended with a partial separation of argentiferous copper bottoms.

4. Ordinary copper ores are roasted with alkaline chlorides, lixiviated with water and weak acid liquor to extract the copper, which is precipitated by iron in the usual way.

5. The concentrated regulus and precipitated copper are subjected to the roaster and selecting process, without refining, in a reverberatory furnace; the product, when argentiferous, being granulated; otherwise it is refined by the ordinary English process, producing an inferior class of commercial copper, which is sold as coarse copper.

6. The granulated argentiferous copper from No. 5 is dissolved in sulphuric acid, producing saleable sulphate of copper, and an argentiferous residue which is worked up by fusion with lead and cupellation, for auriferous silver.

7. The test silver from the different processes, after being burnt fine, is granulated and parted by sulphuric acid, producing ultimately fine gold and silver bars.

The whole of these operations are described in detail. Some of the chief points of interest will be here noticed.

Lead Ore Smelting.—The lead ores may be said to consist of the following minerals:—

	Per cent.
Zinc blende	36·00
Iron pyrites	24·00
Heavy spar	16·00
Galena	14·00
Copper pyrites	1·50
Vein stuff	8·50
	100·00

For the successful treatment of an ore of this class by fusion, it must be as nearly as possible completely desulphurised. On the other hand, the low produce renders it unfit for treatment in ordinary calciners, which would be too expensive. The old method of burning in heaps is therefore maintained, although it has been somewhat modified since the practice of burning the more pyritic portions, forming about one-third of the whole quantity, in the acid works has been adopted. The heaps, having the form of a square-based truncated pyramid, contain from 120 to 125 tons of ore; they are built upon a bed of firewood, and are burnt three times, the first firing requiring from fifteen to sixteen weeks, the second six to seven weeks, and the third three to four weeks. The burnt pyritic lead ores from the sulphuric acid works are added to the heaps in the second firing. The sulphur remaining in the roasted ore averages from 4 to 5 per cent. The principal production of sulphates takes place in the interior of the heaps, the small ore from such points being subjected to lixiviation. The liquors contain sulphates, both of zinc and iron, the latter being converted into insoluble basic ferric sulphates by exposing the liquors to the action of the air for several hours at a nearly boiling heat. These are allowed to deposit, and the purified

liquors, when drawn off, are concentrated, producing crystals of sulphate of zinc, which, when deprived of their water of crystallisation, are saleable. The finished salt contains about 2 per cent. of sulphate of manganese, which is not regarded with disfavour by the purchaser. In the fusion of the roasted ores the chief object is to get rid of the excessive quantity of zinc. For this purpose a very basic slag, containing ferrous oxide and baryta, is required, it having the property of dissolving both oxide and sulphide of zinc—the former in considerable, and the latter in moderate quantity—without losing its fluidity; while a more highly silicated slag, under similar conditions becomes fusible with difficulty and imperfectly fluid. The principal flux therefore consists of the ferriferous slags from the copper ore smelting, containing 45 to 47 per cent. of ferrous oxide, a certain proportion of silicious slags from the Clausthal works and some litharge and dross all containing lead being added to the charge. Coke is used as fuel. The furnaces are two twyer blast furnaces of a four-sided section, about 13 feet high, and are worked with flaming throats to prevent the condensation of the zinc vapour as much as possible. In spite of this, the incrustation of the furnace with zinc oxide proceeds so rapidly that the furnace cannot be kept blowing for more than ten or twelve days. The slags contain ½ to ¾ per cent. of lead. The products are 9 per cent. of furnace lead, and about 2 per cent. of a regulus which is concentrated for copper in the usual way. The former is very impure, and must be liquated from intermixed sulphides of lead and copper before it is fit for cupellation. The purified lead contains about 40 ounces of silver to the ton; it is refined upon the ordinary German cupellation furnace. The average products from 5 tons of furnace lead are 13 lbs. of silver (950 fine and 3 per 1,000 of gold), 40 to 60 cwt. of market litharge, 15 to 35 cwt. of litharge for reduction, and about 30 cwt. of dross and saturated bottoms.

Mixed Ores.—These are generally similar to the lead ores, with the addition of a larger quantity of copper pyrites; the estimated constituents being: zinc-blende 28, iron pyrites 25, copper pyrites 15, barytes 14, galena 11, vein stuff 7 per cent. The smelting process is generally similar to that adopted for lead ores; the sulphur being reduced to 6 or 7 per cent. by roasting; but as a portion of this is removed in the acid works, only two burnings in heaps are required. The heaps contain from 150 to 250 tons. The burnt ores are smelted in blast furnaces 9 feet high, with coke and copper regulus slags as flux, producing lead, which contains more silver and is sensibly richer in gold than that smelted from the purer lead ores, and so-called lead regulus, which is really a coarse copper regulus with 16 per cent. of copper, an equal quantity of zinc, and only 5 per cent. of lead; the latter being principally lost during the subsequent operations of concentrating for copper, owing to the large amount of zinc present.

The slags, which are similar in composition to those of the lead

smelting, remove 0·3 per cent. of lead and 0·75 per cent. of copper, the latter being mainly in the form of included regulus, which, being full of zinc, is not of sufficiently high specific gravity to separate easily from the dense slags when melted. The furnaces, as in the previous operation, are soon choked up with zinc oxide, but can be kept in blast from three to four weeks without cleaning. The operations for concentrating the lead regulus include two burnings in heaps of 100 tons each, the first lasting three weeks, the second two weeks and a half, and a fusion of the burnt stuff in the same kind of blast furnace. As the charge is very rich in iron, a silicious flux is necessary; this is furnished by the pyritic slate or Kniest, which is previously burnt in two fires, and is added to the charge in the proportion of 20 per cent. by weight. The products are concentrated regulus (Kupferrohstein), containing about 40 per cent. of copper and 0·06 of silver, and a speiss-like product, containing 60 to 70 per cent. of copper and 0·25 of silver, alloyed with ordinary arsenic. This latter product is in so far valuable that it effects the concentration of the precious metals in the ore in a comparatively small quantity of copper at an early stage, and thus saves the necessity of subjecting the whole of that metal to desilvering processes. The slags carry away about ½ per cent. of copper.

Rich Copper Ore Smelting.—The mixture of minerals treated corresponds to copper pyrites 45, iron pyrites 25, blende 12, galena 5, heavy spar 7, other vein stuff 6, on a large average, but the composition varies considerably from time to time. It is usual to divide these ores into two classes, the poorer containing from 9 to 15 per cent., and the richer from 15 to 22 per cent. of copper. The former are burnt in the sulphuric acid works, while the latter are treated in the raw state, as it is difficult to roast them from their strong tendency to decrepitate. From one-half to two-thirds of the ores therefore are reduced to 10 per cent. of sulphur; the remainder contains the full amount of 30 to 32 per cent., the proportion being so regulated that the coarse metal of the first fusion should not vary more than from 35 to 45 per cent. of copper. The blast furnaces are of circular section, 9 feet high, 4 feet in diameter at the throat, and 3 feet at the hearth, having four tuyeres. In the charge burnt Kniest is used in such proportion (about 20 per cent.) as will produce a slag with 28 per cent. of silica with 60 per cent. of copper regulus slags, which have no particular fluxing effect, as they contain about the same proportion of iron as the resulting slags, but keep the charge open, and allow a portion of the copper to be recovered.

Coke of medium density is used, 20 cwt. carrying 100 cwt. of burden. About 10 to 10½ tons of materials are smelted daily, the furnaces being kept in blast for six months at a time. The resulting coarse metal contains 41 per cent. of copper and 21·76 of sulphur. The slags retain 0·3 to 0·5 of copper.

The produce of concentrated regulus from the coarse metal requires the latter to be roasted in three fires, or twice if previously

treated in the pyrites burner, to bring the sulphur down to 4 or 5 per cent. The more completely the latter constituent is removed, the greater will be the likelihood of separating a coarse copper rich in gold and silver in the subsequent fusion, which is effected in the same class of blast furnace, and with similar fluxes to the first fusion. The substitution of the South Wales reverberatory furnace is under consideration. The products are coarse copper, some antimony and 0·15 to 0·18 per cent. of silver, and concentrated regulus, averaging 65 per cent. of copper and 0·047 of silver. The slags are added to the charges in several of the preceding operations to recover the 0·6 or 0·8 per cent. of copper they contain.

Treatment of the ordinary Copper Ores.— These are first burnt in the pyrites kilns of the acid works, then subjected to a chloridising treatment, and afterwards extracted by the wet way, according to the process followed at Widnes and elsewhere in England. The chlorination of the burnt ore is effected in reverberatory furnaces by an addition of 15 per cent. of Stassfurth potash salt (and not common salt, as in England). Of the total contents of copper in the roasted material 75 per cent. are found to be soluble in water, 20 per cent. in weak acid, and 5 per cent. in aqua regia. In the extraction, weak liquors of the end of the previous operation are first used for four or five hours, next weak hydrochloric acid from the furnace-condensing towers for twenty-four hours, and finally dilute sulphuric acid for two days.

The dissolved copper in the various liquors is precipitated in the usual way by wrought iron, aided by heat. They require barely two or three hours before the copper is entirely recovered. The precipitate consists on an average of 77·55 of copper and 0·10 of silver. Experiments have been made for the recovery of the latter by Gibb's method, with sulphuretted hydrogen, but up to the present time it has not been systematically adopted. The final residue is an impure purple ore, with about 79 per cent. of ferric oxide, and 0·3 to 0·8 per cent. of copper. It is used as a basic flux for the silicious lead ore of the Upper Harz works, whereby the copper is to some extent recovered.

The cement copper, concentrated regulus, and argentiferous coarse copper represent the three principal intermediate products obtained in the treatment of the ore. The further processes required, are divisible into two classes, according as the material contains silver or not. In the former case it is worked for argentiferous granules, and in the latter for commercial bars. Under present circumstances, about one-half of the total produce, or about 500 tons yearly, are delivered as commercial copper with 0·07 per cent. of silver (23 ounces per ton), the remainder, with 52 ounces (0·16 per cent.), being granulated, passing to the blue vitriol works.

In the treatment of cement copper it is moulded into bricks with coke dust and clay, which when dried are smelted with coal dust in a Welsh reverberatory furnace. A small quantity of regulus is thus

formed by the action of the carbon upon the basic sulphates present, which in the subsequent roasting reacts upon the oxidised copper, producing metallic copper. This is granulated by running it out of the furnace across a stream of water. Considerable care is required in regulating both the pitch of the copper and the temperature to obtain the thin flattened feathered shot required.

When concentrated regulus is treated for the same product, it is roasted in two fires in heaps before fusion. The departure from the regular South Wales practice is due to a wish to avoid the formation of roaster slag, and consequent corrosion of the furnace. In other respects the process is conducted in the same manner as the preceding.

Precipitate copper and regulus poor in silver, and the various classes of copper recovered from the refinery slags, are converted into blister copper and are refined by poling in the usual manner. The product is of a very middling quality owing to the presence of arsenic and antimony which cannot be entirely removed.

The argentiferous granulated copper is dissolved in sulphuric acid to recover the silver. This is effected in conical vats lined with lead, which are filled with the granulated metal, and kept saturated by the acid diluted to 30° Beaumé, which is run in by a siphon from the cistern above at intervals of from three-quarters to one hour. The acid is heated to 70° R. by steam pipes. By this means the metal is exposed to the joint influence of air and acid, the sulphate formed being removed at the next addition of acid liquor. The operation goes on continuously, fresh copper being added as the preceding charge dissolves. The washing is continued until the acid runs off clear. The liquors are received in a series of troughs in which the rough blue vitriol crystallises, the portion deposited nearest the dissolving vat being proportionately richer in silver than that at the end, which contains more gypsum and basic arsenic and antimonic salts. These crystals are drained from the adherent liquor and removed to the refinery pans, which are lead-lined tanks, about 10 feet square and 2 feet deep, heated by flues under the bottom. The rough crystals are dissolved in a portion of the mother liquor from the vats, and heated to 75° R. In order to recover any dissolved silver a small quantity of granulated copper sponge is added. When the solution is cleared and cooled to 65° the liquor is run off to the crystallisers, the argentiferous mud remaining below is removed after every two or three boilings to a basin where it deposits, and the residual liquor is siphoned off, leaving a pasty residue, which is moulded into balls with litharge and cow hair, and melted with a further quantity of litharge and copper slags, producing lead with from 2 to 4 per cent. of silver. The arrangements of this department are so contrived that the mother liquors remain in continuous circulation, and therefore losses of copper and sulphuric acid are avoided, while the quality of the sulphate of copper produced remains unaltered. For this purpose, however, it is necessary that the copper treated should be free from iron and nickel. The average pro-

duction of crystallised sulphate of copper per 100 lbs. of copper treated is 380 lbs., which requires 340 lbs. of acid at 50° B. The plant in use, comprising six dissolving vats, two boiling pans, and twenty-four crystallisers, turns out from 28 to 30 per cent. of crystallised sulphate in twenty-four hours.

Parting.—The total production of test silver is 50 to 55 cwt. per annum, of an average fineness of 950 silver and 5 gold per 1,000, the whole of which is parted at Oker works. In the first instance the cake silver is refined in 50-lb. charges, upon small tests under a muffle, to remove lead, bismuth, antimony, and other impurities; when sufficiently fined, it is granulated in water and finally dissolved in sulphuric acid. The latter operation is effected in slightly bulbed porcelain vessels, which are protected by a coarse wire network coated with clay and hammer scale. As a further protection, they are not heated directly by the fire, but placed in a cast-iron pan forming a hot-air bath. The cover is secured by a water joint, and a lead tube conveys the sulphurous acid vapours into the chimney; four parting vessels each receiving a charge of 12½ lbs. of granulated silver, and twice that weight of concentrated acid (66° Beaumé), are in use. The firing is conducted cautiously, six hours being required to dissolve the silver; if great care is not exercised in this particular, the porcelain vessels are easily broken. When the solution is finished and the gold has had time to deposit, the liquor is run off into pans, where the sulphate of silver solidifies on cooling. This is carefully redissolved in warm water, and strips of copper are suspended in the solution to separate the silver. The cement silver, after washing and pressing on linen, is moulded into blocks in a screw press, which are melted in quantities of 75 lbs. in blacklead crucibles, with a small addition of nitrate of soda. The residue of gold, which is purer than that usually obtained when cast-iron parting vessels are used, is boiled a second time with strong acid, and finally washed with water until no further silver reaction is apparent, when it is collected and dried in a porcelain capsule. When a quantity of about 10 lbs. has accumulated, it is melted in a blacklead pot with a small addition of borax glass. The resulting bar gold assays 985 fine. H. B.

On the Relative Value of Belgian and other Iron Ores.

By A. Habets.

(Revue universelle des Mines, vol. i., 1877, p. 504.)

This is a lengthy investigation of the relative values of iron ores, as determined by the qualities of pig iron that may be made from them, and the proportionate cost of the fuel, lime, labour, and other items that are required in the process.

The character and value of pig iron depend essentially on the

amounts of foreign substances that it contains, and on the working condition of the blast furnace in which it is produced. These foreign substances are derived chiefly from the ore used, and only to a minor extent from the coke and limestone added to it. Ores are thus conveniently classed according to the qualities of pig iron that may be obtained from them, or, in other words, the amount of such substances in proportion to their yield of iron. The elements in an ore that chiefly affect the character of the metal were then noticed; and the Author, after discussing at some length the effects of these on the properties of the metal, and the proportion of the total amount of each in the ore found in the pig iron made from it, gives a classification of the varieties of forge and steel-making pig iron manufactured in Belgium, in accordance with their fitness for one or other of which the different ores may be grouped. The proportion of foundry iron produced in the country is so small that it need not be separately considered; as the greater or less fitness of ores for making it does not sensibly affect their price.

The Author, after this introduction, discusses successively the average prices of the different classes of pig iron, the consumption of ore, limestone, and coke, in making them from ores of different richness and under different conditions of working, and the amounts to be allowed for labour and sundry charges; and deduces from these data a series of general formulæ for the value of different ores, assuming that the prices of the coke, limestone, and pig iron are given, and that there is a profit of 10 per cent. on the manufacture. No note is taken in these formulæ of the physical properties of different ores, their fusibility, brittleness, or more or less fine state of division, nor of the greater or less facility with which they are reduced.

The values are next calculated of such ores as are too impure to be treated alone, and can be used only in admixture with others; and the Author, in conclusion, gives analyses of twenty-five of the principal native and foreign ores that are treated in Belgium, and works out in detail their values, corresponding to different prices of pig iron, limestone, and coke. The variations of these values, for different prices of coke and for differences in the richness of the ores, are expressed graphically in a series of plates accompanying the Paper.

W. H.

Different Qualities of Iron and Steel. By C. Grauhan.

(Zeitschrift des Vereines Deutscher Ingenieure, vol. xxi., Nos. 7 and 8.)

The Author describes at full length the characteristics of the different species of steel and iron. Of steels he mentions puddled, Bessemer, Martin, and cast steel, pointing out that generally the

first has the coarsest and the last the finest grain; puddled steel generally shows some traces of having been formed of several pieces, while Bessemer and the other qualities, being cast in blocks, are homogeneous. But Bessemer metal is frequently porous, and when worked up for railway axles or similar purposes, the bubbles are first closed by forging, but show themselves again in the form of longitudinal cracks when taken out of the lathe. These bubbles occur seldom in Martin steel, never in cast steel. And a further difference between Martin and Bessemer steel is, that the former contains less silica.

According to the Author, the quality of steel cannot be fairly tested unless it is first hardened, as otherwise a bar which was rolled rather hotter than another would show quite a different texture, although of the same metal. The steel should be heated, forged to bars of a uniform size, and then hardened in water, which process eliminates any chance differences. If a bar thus prepared be broken, the texture, colour, and general appearance of the fracture will give a very close approximation to the quality. Of course, although fine-grained steel is better than coarse-grained, the former cannot be used for every purpose. Rails and axles, for instance, require coarse-grained, porous, and soft metal. If after sudden immersion in water the grain is as coarse as before, the steel is not fit for hardening and approximates to wrought iron. The finer the grain the harder is the metal and the more carbon does it contain. If the fracture shows a coarse grain and a whitish reflection there is a good deal of phosphorus and silica in the steel, which is of course injurious. If it shines blue instead of white the metal is burnt and contains too little carbon.

As a rule, the hardness of steel depends on the amount of carbon it contains, and the quantity of carbon resulting from analysis is used as a measure of its hardness.

Herr Grauhan mentions the different methods of testing iron, of which he prefers the chemical mode, and gives the following results of the analyses of various sorts of iron:—

1. Westphalian Bessemer Iron.

	Per cent.
Iron	86·912
Carbon	3·200
Silicium	3·140
Manganese	6·180
Phosphorus	0·120
Sulphur	0·070
Copper	0·380

2. Welsh Iron (white).

Iron	94·400
Carbon	2·400
Silicium	0·800
Sulphur	0·700
Phosphorus	1·500
Manganese	0·200

3. Spiegel Iron from Müsen.

	Per cent.
Iron	82·860
Carbon	4·323
Silicium	0·997
Manganese	10·707
Phosphorus	0·059
Sulphur	0·014
Copper	0·066

4. Bessemer Rail from a Westphalian Works, which broke in unloading.

Carbon	0·370
Manganese	0·650
Silicium	0·223
Sulphur	0·040
Phosphorus	0·084

5. Cast-steel Axle from a Westphalian Works.

Carbon	0·221
Silicium	0·061
Phosphorus	0·052
Sulphur	0·072
Manganese	0·276
Copper	0·072

6. Retort-steel Tire of a Westphalian Works.

Carbon	0·5800
Sulphur	0·0380
Silicium	0·1010
Phosphorus	0·0407
Manganese	0·6080

N.B.—The tenacity of this tire was 71 to 74 kilogrammes per millimètre, or about 43 tons to the square inch.

E. d'A.

Proposed General Classification of Iron and Steel.

(Organ für die Fortschritte des Eisenbahnwesens, vol. xv., p. 35.)

This proposition emanates from a sub-committee of the German Railway Union, appointed for the purpose, and takes the form of a report presented to the general meeting of the Union at the Hague, July 1877. The meeting agreed to act on this report, both by bringing influence to bear on various governments, with the view of having such a classification definitely fixed and agreed upon, and also by instituting further experiments in order to render the classification more exact.

The sub-committee's report first enlarges on the desirability of such a classification, and especially mentions the great inequalities now found to exist among different specimens of iron and steel, supposed to be of similar make, owing to an ignorance of the laws under which differences of quality are produced. It observes that such a classification might require revision from time to time, and

then proceeds to give a table which it considers to be as perfect as can be attained in the present state of knowledge. The two qualities specified throughout are strength, as represented by the tensional breaking strain in kilogrammes per square centimètre, and ductility, as represented by the percentage of contraction of area at the breaking point.

The table is as follows:—

——	Tensional Strength. Kilogramme per Square Centimètre. = ·00635 Ton per Square Inch.	Ductility. Contraction per cent.
A. Bessemer steel, cast steel, or Siemens-Martin steels used as a material of construction for rails, axles, tires, &c.		
1st Quality Class *a*. Hard	6,500	25
1st Quality „ *b*. Medium . . .	5,500	35
1st Quality „ *c*. Soft	4,500	45
Fracture to be uniform, and no cracks visible in the broken ends.		
2nd Quality Class *a*. Hard	5,500	20
2nd Quality „ *b*. Soft	4,500	30
Fracture, &c., as above.		
B. Bar iron.		
1st Quality	3,800	40
2nd „	3,500	25
C. Plate iron.		
1st Quality with the grain	3,600	25
1st Quality across „	3,200	15
2nd Quality with the grain	3,300	15
2nd Quality across „	3,000	9

All material which falls below these limits it is proposed to distinguish as "non-classified" material.

The above classification would not of course do anything towards solving the question which class of material is the most fitting to use for any particular purpose. This requires a much more extensive range of experience and of tests, and the report concludes by strongly recommending that an Office of Research (Versuchsanstalt) should be established by government with the special object of investigating such matters.

W. R. B.

The Siemens-Martin Process at Gratz. By J. Prochaska.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, vol. xxvi., p. 115.)

The importance of this process for the Austrian Alpine lands has not, in the Author's opinion, been sufficiently recognised, and

notwithstanding the disrepute attached to the failure of certain works established for carrying it out in the district, it will in most cases be found to be well suited to the requirements of the country where excellent coal for gas production and a high class of scrap and waste iron can be readily obtained; while, on the other hand, the difficulty of producing suitably grey pig iron stands in the way of the further development of the Bessemer process. The selection of one or other method should be solely governed by the cost of the raw material; when steel or iron scrap, of good and pure quality, can be obtained at or below the price of Bessemer pig iron, the Siemens-Martin process is, according to the Author, to be preferred, as it has the further advantage of producing less waste, and with practice can be worked with almost mathematical certainty, especially in producing the mildest qualities of metal. For an equal annual production, the first cost and expenses of maintenance are also smaller with the Siemens than the Bessemer process.

The results given in the following paragraphs have been obtained at the new steel works attached to the rolling mills of the South Austrian Railway Company at Gratz during the past nine months :—

The works include eight gas producers, fed with Leoben coal, four being assigned to each melting furnace; the gas passes below the floor through horizontal regenerators. There are two steel furnaces, each taking a 10 ton charge. They differ in construction from those previously used in two points, namely, in gas and air admission passages, which are so arranged that the actual combination of the two currents and the ignition of the gas only takes place in the hearth of the furnace, and the direction jet of flame, which has a strong downward inclination. The first protects the walls and roof from the cutting action of the flame, whereby their durability is increased at least threefold, while the second facilitates the decarburizing action on the bath of metal. In consequence of these changes, the cost of maintenance of the furnaces has been considerably reduced, and the number of charges that can be worked without necessitating repair of the brickwork has been raised from thirty or forty to between one hundred and fifty and two hundred and thirty. The charges, before introduction into the melting hearth, are subjected to a preliminary heating in a special furnace with a Bicheroux gas generator, fed with small slack, which also heats a steam boiler. The cost of the works, including buildings, was £9,563. The results obtained during the last month of constant working of both furnaces were as follows :—

In twenty-eight working days the melting furnaces used 553 tons of large coal and the heating furnace 287 tons of slack; ninety-six charges were made, including 256·4 tons of pig iron, of which 20 per cent. were white iron, 706·6 tons of malleable scrap and steel rails, and 35·2 tons of spiegeleisen, or a total of 998·2 tons. The products were three thousand three hundred and sixty-four

steel ingots, weighing 955·4 tons, and 2 tons waste, or 957·4 tons total weight. The corresponding percentages per one hundred of steel ingots produced are, therefore—large coal 57·7, slack, 29·9; total coal, 87·6 per cent. Malleable iron, 73·8; pig iron, 26·8; spiegeleisen, 3·8; total iron, 104·4 per cent. These results contrast favourably with those obtained at the same place with a furnace taking 5½ ton charges, when the consumption of coal was 137, and of iron 109 units per 100 units of steel produced.

The annual output of a furnace of the larger size may be taken at 6,000 tons. By far the larger portion of the steel produced is converted into rails; its chemical composition, on an average, varies between the following limits per cent.:—

Carbon, 0·30 to 0·40; phosphorus, 0·08 to 0·12; silicon, 0·01 to 0·02; manganese, 0·10 to 0·25. The quality of the rails is irreproachable, the number of wasters made rarely exceeding one or two per month. The production of soft iron with 0·18 to 0·22 of carbon is unattended with any special difficulty if the furnace is kept at the highest possible temperature. When the metal is required for castings, an addition of siliciferous pig iron is found to be very beneficial, steel so produced containing—carbon, 0·65; silicon, 0·15, and manganese 0·34 per cent., yielding perfectly sound and dense castings.

In addition to complete analysis of all the materials charged, the course of the operation is checked by Eggertz's carbon test, and two special examinations for phosphorus and manganese by methods which are deserving of notice for their simplicity and rapidity in execution. In the first of these the iron solution is heated with molybdic acid in a calibrated tube of small bore, and the phosphorus is calculated from the observed volume of the precipitate, which can be done in from two and a half to three hours. In the second or manganese determination, the iron solution, after serving for the Eggertz carbon test, is digested with red lead, well boiled for a few minutes, cooled by dilution with distilled water, and filtered by aspiration through an abestos filter. The determination of manganese is made on the filtrate volumetrically by a weak solution of sulphate of iron. The time required is about half an hour. H. B.

NOTE.—This method of manganese determination depends upon the formation of permanganic acid, when a solution of nitrate of manganese is treated with peroxide of lead P_6O_9, or the dark brown residue obtained when red lead is digested with nitric acid. The latter compound has been used for many years as a very delicate qualitative test for manganese by the strong pink colour produced in the solution: but it does not appear to have been regularly used for quantitative determinations before.—H. B.

Experiments with a Coal-cutting Machine at Polnisch-Ostrau.
By J. MAYER.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, vol. xxv., pp. 461, 471–488, 498, 506.)

The Author, in the earlier part of this memoir, reviews the construction of, and results obtained by, various systems of coal-cutting apparatus adopted in other places, before proceeding to describe the machine experimented upon, which is a modification of that by Hurd and Simpson, constructed by Slanek and Reska. The seam worked is 2·29 to 2·46 feet thick, and has a dip varying from 11° to 17°, the coal is hard but rather brittle, making a good deal of slack. The average work of a good collier holing in this seam is from 1·8 square yards to 2·15 square yards per shift of eight hours. The machine has a cutting wheel of 3 feet 9 inches diameter, driven at seven revolutions per minute, by a pair of engines 6 inches in diameter and 12 inches stroke, making 120 revolutions per minute, under a pressure of air of four atmospheres at the compressor, which corresponds to about 7 H.P. The cut is from 31½ to 39 inches deep, about 3 inches high, and was originally intended to be carried forward at a speed of 11 inches per minute, but the hardness of the coal has necessitated a diminution of speed to 7·8, or 9·8 inches per minute. At the latter rate the surface cut per hour would be 9·68 square yards, or, for the whole shift of eight hours, 77·4 square yards. This cannot, of course, be realised in practice, the maximum result, supposing the machine to be continuously at work, being from 36 to 48 square yards, or a quantity equal to the work of from sixteen to twenty-five men. The cost of the two methods, deduced from the results of cutting 358·8 square yards, the seam yielding 255 tons of coal, was—

	s.	*d.*	
By the machine	2	8 3/10	per ton.
„ hand labour	2	9 1/3	„

The first amount includes a sinking fund charge of £3 per week on £1,000, the cost of the compressor being taken at £400, the machine at £400, and the air pipes at £200, the annual work being put at 10,200 tons. The cost of laying out a working face for the machine for a length of 328 yards rather more than counterbalances the small saving as compared with hand labour; but the actual profit is, according to the Author, to be derived from the increased amount of large coal obtained, which was about 10 per cent., and on a final balancing of figures the advantage gained by the machine appeared to be about 3½*d.* per ton. With this there is a considerable saving in the quantity of labour required, three hundred and eighty-five shifts being employed for all purposes when the coal is cut by hand, and two hundred and seventy-two when cut by machine, or a saving of 30 per cent. If, however,

the work employed in actual coal-cutting is alone considered, the saving is about 60 per cent.

In a general review of the results, the Author points out that as the advantage of machine cutting is chiefly realised by a reduction in the amount of slack made, it is only in thin and hard seams that any great saving is to be looked for, and it is precisely those seams that are least workable and must be abandoned in a season of low prices. A good roof and tolerably uniform dip are also necessary, and as these desiderata cannot always be obtained, the use of machines of this kind must necessarily be restricted. A lighter class of machine (that described weighs 35 cwt.) suited for short lengths of face, and available for use in pillar workings, would probably be more useful, even though capable of doing less work in a given time than those at present in use. The other extreme of making excessively light machines to be worked by hand should, however, be avoided, as the power required for holing in coal, even along short lines of face, is too considerable to allow of manual power machines being successful in practice.

H. B.

Rotative Water-Pressure Blast-Engines. By W. Jones.

(Journal of the Franklin Institute, vol. ciii., p. 398.)

This engine, horizontal and direct-acting, was constructed to the designs of Messrs. Taws and Hartman, for the Longdale Iron Company, Virginia, to supply blast for a coke furnace. There is a pair of blowing cylinders, 48 inches in diameter, to each of which an 18-inch water-cylinder is connected direct, with a stroke of 5 feet. The admission and discharge valves for the water-cylinders are 18 inches in diameter, equal to the diameter of the cylinders, conducive by their largeness to steadiness of motion. The valves are moved by means of ordinary eccentrics and rods. The two engines are coupled to one crank-shaft, carrying two fly-wheels. The water is taken from a dam having a head of 65 feet, from which the available supply is ordinarily about 6 cubic feet per second, through a plate-iron flume 30 inches in diameter. The main supply-pipe, ending with a diameter of 24 inches, is terminated by an air-vessel 2 feet in diameter and 9 feet high. A branch is taken to each water-cylinder, and carries an air-vessel 10 inches in diameter and 9 feet high. The exhaust water is discharged by a pipe into the waste water-way, 13 feet below the cylinders, making a total head of (65 + 13 =) 78 feet.

The engines make twelve turns per minute, noiselessly and without shock; speed of piston, 120 feet per minute. The pressure of the blast is 3½ lbs. per square inch. It is shown by indicator diagrams that the pressure in the water-cylinder is steady and constant throughout the stroke; and that during the exhaust it falls to a pressure of 5·625 lbs. per square inch below the atmospheric

line, equivalent to 13 feet of water, the actual fall below the cylinders. The efficiency of the engines as originally made was calculated as 84 per cent. But the water-cylinders have recently been lined, and reduced to a diameter of 15¾ inches, making twelve turns per minute, and giving a blast of 2⅞ lbs. per square inch. The efficiency has thereby been reduced to 79 per cent. The furnace supplied by the blast is 11 feet in diameter at the boshes, and 60 feet high, with a closed top; and yielding from 130 to 150 tons of coke-pig per week.

D. K. C.

On the Composition and Industrial Use of Furnace Gases.

By M. Cailletet.

(Comptes rendus de l'Académie des Sciences, vol. lxxxv., p. 955.)

The labours of M. H. St.-Claire Deville on dissociation, by opening a new path to scientific research, have led to the interpretation of a great number of metallurgical phenomena otherwise inexplicable. Collecting gases circulating in the most heated parts of furnaces working iron, the Author has established the fact that these gases rapidly cooled differ completely from the results given by the analyses of Ebelmen. This able metallurgist, ignoring the phenomena of dissociation, collected the gases by slowly aspirating them through a long tube which allowed the combination of the dissociated elements. In Ebelmen's analyses the reaction nearly always appears complete, whereas the Author finds that the fumes and carburetted gases may exist in the presence of oxygen and at the temperature of molten iron. Gas collected above the grating of a furnace where the bricks were at a temperature of intense white heat, contained, oxygen 13·15; carbonic oxide 3·31; carbonic acid 1·04; nitrogen (by difference) 82·5, per cent. In metallurgical works the gases issuing from the furnaces are generally directed beneath steam generators, but they cool very rapidly against the sides of the boiler; so that after traversing about 50 feet the temperature is lower than 500°, and the gases then contain, per cent., oxygen 7·65; carbonic oxide 3·21; carbonic acid 7·42; nitrogen 81·72. The quantity of oxygen has thus diminished by nearly one-half, and has been lost by its reaction on the finely-divided carbon which exists in great quantity in the atmosphere of the furnace. The Author's researches have led him to establish at his Works at St. Marc (Côte-d'Or) a kiln of large size, which receives the gases as they issue from the generator. Arriving in this kiln or oven, of which the section exceeds 32 square feet, the gases lose much of their velocity, while, at the same time, they are ignited by passing over a small grate on which is burning some cheap combustible. The elevated temperature so obtained is utilised in the annealing of

sheet iron. By heating by this means, for about twelve hours, sheets that have been oxidised in the annealing furnace, the oxide has been completely reduced, leaving the surface clear and bright.

P. H.

Lubrication with Neutral Oils in Steam Engines with Surface Condensation. By O. Allaire.

(Comptes rendus de l'Académie des Sciences, vol. lxxxv., p. 929.)

M. Hétet[1] accounted for the deposits in surface condensers and boilers fed from them by the saponification of fatty substances under the action of steam. The trials which have recently been conducted at Cherbourg complete the investigations of M. Hétet. From the Report of the Admiralty Committee it appears that, whilst the oils hitherto used for the lubrication of cylinders yield a residue equal to about 50 per cent. their weight, containing more than half its weight of oxide of iron, an oil which is purified of free acids (neutral refined oil) yields only 19 per cent. of residue, which contains only 6 per cent. of oxide of iron. These compound ratios result in showing that the quantities of iron-oxide produced in the two cases, for equal weights of lubricant, are as 25 to 1; whereas M. Allaire argues, if the oils had been subject to saponification by steam, without alkali, equal quantities of deposit should have been generated. All oils, without exception, even such as have not been treated with any acid, contain, he maintains, a high proportion of free acids; and to these acids he ascribes the formation of deposits.

Referring to M. Hétet's system of employing lime, there is no doubt that decomposition by the agency of steam is produced in the presence of lime, and there is yielded a greater amount of deposit than if it be not employed at all. True, there is a harmless oleate of lime, instead of oleate of iron; but there is the aggravated disadvantage of reducing the action of the condenser by the coating of the tubes by the deposit.

M. Hétet, replying (same vol. p. 1,054) to M. Allaire's article above noticed, states that he found that the proportion of acids in lubricating oils rarely averaged more than 5 per cent., which was not sufficient to account for the enormous deposits of ferruginous soaps in steam boilers. The saponifying action attributed to chalk is inadmissible, considering the extreme state of dilution of solutions employed by him, and the low temperature, 104° Fahr. Besides, the fatty matter is neutralised at the outlet from the condenser, where the chalk is not present, and the deposits in the

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xliv., p. 284.

condenser must be due to some other cause. M. Hétet insists that, by his process, boilers are preserved from attack, and do not contain any free grease.

D. K. C.

On the Use of Zinc as a Disincrustant.[1]

By M. Brossard de Corbigny.

(Annales des Mines, vol. xii., pp. 155–164.)

M. Lesueur recently presented to the Minister of Public Works and to the Academy of Sciences a Paper upon the use of metallic zinc as a preservative from incrustation in steam boilers. The Minister of Public Works charged the Author with the investigation of the merit of the proposed method. The application of the process consists simply in placing in the boiler a quantity of metallic zinc. The boiler is filled and worked in the usual manner. When the water employed encrusts only slightly, the deposit, instead of forming a solid and adherent crust, remains in the state of a liquid mud, which a simple washing or blowing out suffices to remove. When the incrustation is rapid, the deposit is strong and coherent as if zinc had not been used, but this deposit is not adherent and can be removed by hand, or, at least, detached without great effort. "Picking" is avoided. As to the zinc itself, it would be incorrect to say that it disappears; it is transformed into an earthy and white mass chiefly consisting of oxide of zinc. A slow oxidation has taken place producing a pseudomorphosis of zinc into oxide of zinc. A sample of such deposit from a boiler fed from the water of the Loire gave—water, 1·60; zinc oxide, 87·30; iron oxide and alumina, 3·80; sand and earth, 1·60; carbonate of lime, 6·20; and of magnesia, 0·50, in 101 parts. On the other hand, not the least trace of zinc is found dissolved in water taken from the boiler, and but small quantities are to be found in the deposits. In an abundant and solid deposit from a boiler fed from a well in the neighbourhood of the Maine, there were found—carbonate of lime, 75·60; of magnesia, 3·00; sulphate of lime, 9·33; sand and earth, 8·40; iron and zinc oxides, 4·20; chlorides, 0·40; in 100·93 parts. The results are not however the same with selenitous or selenitic waters as with calcareous waters; in this case the addition of zinc does not appear to have given distinctive results. The Author suggests that a larger dose of the zinc might have given better effect, but that then the use of this metal would not have been economical. The theoretical explanation of the action of the zinc is the formation of a continuous film of bubbles of hydrogen gas upon the boiler plates, which film prevents the adhesion of the deposit. Experience has shown that it is convenient to employ for each period of activity of the boiler about

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlii., p. 329.

2·2 lbs. of zinc per HP. (French).[1] The chemical equivalent of 2·2 lbs. of zinc is 77 gallons of hydrogen, which is disengaged progressively upon each square mètre (10·764 square feet) of surface with a reduction of volume corresponding to the interior pressure. If the pressure is 5 atmospheres the gaseous volume will be reduced to 15 gallons, which will form a thin stratum between the boiler sides and the incrustation. These figures, though small, the Author believes may justify the explanation. The Paper includes the consideration of the influences of various kinds of water occurring in France as found from experience; and the following conclusions are arrived at. The use of zinc is of incontestable benefit with calcareous waters that are not too hard, of which the hydrometric degree marked is not more than 25° to 30°. The deposits lose their cohesive property and "picking" is avoided. With selenitous waters of 40° and higher the result is insignificant. The zinc is preferably used in ingots of 0·55 lbs. to 2·2 lbs. per HP. for a period of several months, varying with the water employed. It may be placed in any part of the boiler where not influenced by direct firing.

P. H.

Sugar-Cane Crushing Mill. By Lieutenant J. CLIBBORN.

(Professional Papers on Indian Engineering, October 1877, p. 365.)

The water-wheel and mill recently erected at the Bhaisáni Falls, on the Ganges Canal, were constructed entirely of wood, in the simplest and cheapest manner, and erected in the midst of the sugar fields. The simplicity of the mill is due mainly to the fact that the shaft of the water-wheel performs the duty of the upper roller of the mill; whilst the two lower rollers are driven by wooden gear direct from the shaft. Grooves, ½ inch deep, are cut in the rollers at each end, to prevent the juice from flowing off at the bearings. The water-wheel is 12 feet in diameter, and 5 feet wide. The main shaft is of sissú wood, 18 inches in diameter at the rolling portion, and hexagonal in the wheel; it is supported in bearings of kikar wood, bolted down to a framing of shisham or bakera, fixed in the masonry of the falls. The cog-wheels are made of a block of sissú, having kikar teeth dovetailed into them, and two rings of wrought iron shrunk on at each end. A little black lead applied occasionally is all that is required for lubrication. The bearings should be kept dry; and the surface-speed of the rollers should not exceed the rate of 20 feet per minute. It was found necessary, after a year's working, to cover the rollers with kikar wood on end, 3 inches thick, dovetailed into the rollers: this plan appears to answer well.

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[1] The French "cheval vapeur" = ·9863 HP.

The mill crushes 1 maund (82¼ lbs. Bengal measure) of cane in four minutes, yielding 50 per cent. of the weight of the cane in juice; and it is calculated that, in a working season of three months, the mill would crush the crop from 72 bighas (45 acres), allowing 200 maunds of juice to the bigha (⅝ acre). The cost of the mill is estimated at 700 rupees (about £70): and the total working expenses for the season at 300 rupees (£30). An illustration of the mill accompanies the article.

D. K. C.

Hydrographic Conditions of the Vistula, Oder, Elbe, and Rhine.

By H. RODDE.

(Deutsche Bauzeitung, vol. x., p. 410.)

The alteration in the conditions of the German rivers during recent years, and the frequent and violent floods alternating with prolonged periods of extreme low water, have induced the Author to attempt a new and accurate method of showing the levels of the water in a river by a series of curves. Instead of assuming as correct the zero points above which the levels of the water have hitherto been measured at different places, he establishes a mean water-level for one point in the course of each of the four rivers in question and uses this level as his horizon. These horizons are ascertained by observations of the water-levels extending over sixty-four years (from 1812 to 1876), the mean for each day being first calculated, then the mean for each year, and finally the mean for the whole period. Taking these lines as bases, the Author measures off the days as abscissæ and marks off the mean heights of the river on each of these days as an ordinate; connecting these points, he obtains a first curve, and by proceeding in a similar manner to mark off a second series of points indicating the highest, and a third to indicate the lowest, level of water on each day, he obtains two more curves: the work being completed by a curve showing the mean rise or fall of each river during each successive month. The curious result of this statistical diagram is that the four curves are very similar on all four rivers, and, in fact, are in many cases absolutely identical. But the Author points out that, though it may be assumed, with respect to the Oder, Elbe, and Vistula, that the observations here noted give a fair approximation to the various rises and falls of the whole river during the period of sixty-four years, albeit confined to one point only, yet this is not the case with the Rhine, which, from Strasburg downwards, has quite a different regulation to that prevailing in its upper portion. This arises, of course, from the great orographical variety of the countries through which the Rhine passes, and from the totally different climates, conditions of the Alps, and of the low mountains or hills from which the other three rivers spring. Herr

Rodde therefore points out the necessity of carrying out a similar series of observations at other points of the rivers, so as to obtain reliable data for river and navigation works.

E. D'A.

Improvement of the Entrance to the Port of Rotterdam.

(Sulle opere idrauliche dei Paese Bassi. Relazione di Missione a S. E. il Sig. Ministro dei Lavori Pubblici dell' Ingegnere Italo Maganzini.)

These works were necessitated by the silting up of the various channels by which the town was formerly approached, viz.:—

1. The "Brielsche Zeegat," or Brielle mouth of the New Meuse and Scheur. This was the most direct approach, and being navigable for vessels of considerable draught, it was generally used during the early part of the century. In 1850, however, the depth of water had decreased to about 11·5 feet, and its use was abandoned. Ships entering by it passed to the south of the island of Rosenburg, and up the New Meuse to Vlaardingen and Rotterdam.

2. The "Goereesche Zeegat," and "Brouwershavensche Zeegat." After the Brielsche Zeegat had become impassable, vessels outward bound from Rotterdam, descended the New Meuse to Vlaardingen, but instead of continuing their course towards the sea, turned eastward and followed the Old Meuse to Dordrecht, from thence passing by the Dordsche canal into the Hollandschdiep, and so by the Haringvliet to the Goereesche, or by the Krammer to Brouwershavensche Zeegat. These channels, though much longer, were little more convenient than the old one, and were only available for ships of moderate draught; the maximum depth in the Goereesche not exceeding 18·7 feet, and in the Brouwershavensche, 17 feet. The shorter passages by the Noord, between Rotterdam and Dordrecht, and by the Spui, between the old Meuse and Haringvliet, did not admit draughts exceeding 12·1 feet.

As early as 1827–1829, a canal was cut through the island of Voorne, between Nieuwesluis and Hellevoetsluis, at a cost of £132,800 in order to avoid the increasing difficulty of the Brielle route, but owing to its insufficient depth, 16·9 feet, and to the loss of time and money incurred in passing the locks at each end, it was little used.

In 1857 the necessity of making an immediate and radical improvement in the means of communication caused the Government to appoint a commission to consider the whole question. The following proposals were submitted to the Commissioners:—

1. The improvement of the Brielsche Zeegat by the construction of a masonry mole 8·8 miles long, extending seawards from the south-eastern corner of Voorne to a depth of 16·4 feet below L.W. line. Estimated cost, £622,500.

2. The deepening of the existing Voorne canal, and the excava-

tion of a new cut through the island of Goeree, thus opening a direct channel from the Brouwershavensche Zeegat to the new Meuse. Estimated cost, £271,076.

3. A second proposition for the improvement of the Brielsche Zeegat, by the erection of two parallel moles in masonry, together 11·8 miles long, running seawards to a depth of 16·4 feet below L.W. Estimated cost, £755,300.

4. A third proposal for the re-opening of the same entrance, by the construction of two moles, shorter than those last mentioned, but otherwise similar to them. Estimated cost, £594,280.

5. The improvement of the navigation between Krimpen and the coast by the regulation of the New Meuse to Vlaardingen; of the Scheur along the northern shore of Rozenburg, and by the excavation of a canal, through the dunes of the Hoek van Holland, to carry the waters of the last-named river to the sea, the old bed being at the same time closed by a dam. This project was submitted to the Commission on the 25th of January, 1858, by Inspector P. Caland, and, after some modification in the details, was finally approved by them in 1859. The cost of the works was estimated at £537,900. On the 24th of January, 1863, a law was passed authorising the commencement of the works, and fixing the width of the channel at 738 feet at Krimpen, increasing gradually to 1,476 feet at Vlaardingen, and to 2,952 feet at the coast. The slopes of the canal through the dunes were to be protected by fascine work, and the entrance by two moles, or jetties, advancing into the sea some distance beyond the 5-mètre line of soundings, which here approaches to within about 1,000 mètres of the shore. The works are now practically finished. The southern mole, commenced in 1864, is 7,544 feet long, and the northern, begun in the previous year, 6,560 feet. The canal across the Hoek van Holland was begun in the early part of 1868, by the excavation of a channel of reduced section, which, however, was not carried through to the sea, the excavation of the remaining part, as well as the widening and deepening of that already cut, being left to the action of the current, which was gradually increased by the closing of the Scheur. On the 28th of October in the same year, the last barrier of sand yielded, and since that time the depth and width of the channel have continually increased; for while in 1868 the sectional area below L.W. line was only 1,614 square feet it now exceeds 15,064 square feet. From a Paper read before the Royal College of Engineers by Inspector Caland in 1871, it appears that, up to that date, the quantity of matter removed by the action of the current was already five times as great as that excavated artificially. The depth is now as much as 49·2 feet in places, and the width, although at present less than that specified, is gradually increasing.

The regular navigation of the new channel commenced in 1870. The bank across the Scheur was commenced in 1688, but the channel was not actually closed till 1871. The bed of the river between Krimpen and Rotterdam has also been regulated, such regulation being rendered necessary by the existence of an obstruc-

tion to the free passage of the tide between the two places, which caused a depression of the water level at Rotterdam during the ebb-tide, and the reverse during the flood.

The total expenditure on the works up to August, 1876, has been £857,276, while the saving effected in the cost of navigation is given by Inspector Caland as £2,324 per month.

M. L.

Land Reclamation on the Coast of Friesland.

(Sulle opere idrauliche dei Paesi Bassi. Relazione de Missione a S. E. il Sig. Ministro dei Lavori Pubbliche dell Ingegnere, all. del Genio Civile Italo Maganzini, p. 169.)

With a view of reclaiming the land lying between the northern coast of Friesland and the island of Ameland, about 7½ miles distant, a concession was obtained from the Netherlands Government on the 16th of October, 1869, for the construction of an earthen bank, with slopes of 10 to 1, and a top width of 19·7 feet, from a point halfway along the southern shore of the island to the mainland, which, by obstructing the flow of the tide through the channel, should favour the deposition of matters held in suspension by the water, and so cause a gradual shoaling of the bottom. The height of the crest was originally fixed at 1·64 foot above H.W., but was reduced before the commencement of the works by 3·28 feet, or to 1·64 foot below L.W.; while the top width was increased to 111·5 feet, and the ratio of the slopes to 14:1. Subsequently, however, it was found necessary to modify the design by strengthening the work with fascines, and protecting the slopes and crest with stones. The first stratum of fascines was laid in 1872, and the work advanced so well, that in the autumn of 1874, it had reached to within 3·28 feet of L.W., causing already a considerable accumulation of deposit, especially near the two ends.

In 1875 the crest was within 2·5 feet of H.W. line for 7,854 yards out of the total length of 9,100 yards, and the bottom had risen in places to 5·73 feet above L.W. In the following year it was possible to pass across the bank dryshod. The exact positions of the banks, by which the reclaimed land will eventually be protected, are not yet fixed, but they will run from the eastern and western extremities of the island to the mainland. The area enclosed will lie between 29,650 and 61,770 acres. The undertaking should be a very profitable one, as the coast line renders embankment unnecessary on the two longest sides of the area, and the reclaimed land, being above L.W. level, can be drained without the aid of pumping machinery.

M. L.

Tidal and Stream Observations on the West Coast of Schleswig. By C. G. Bruun.

(Zeitschrift des Architekten- und Ingenieur-Vereins zu Hannover, vol. xxiii., p. 427.)

This Paper contains an account of tidal observations, current measurements and surveys, made in the year 1863, among the islands on the west coast of Schleswig, with a view to the construction of works for the more effectual protection of the coast from the incursions of the sea.

The observations were confined to a single tide at each of the places of principal importance to the object in view; yet the Author is satisfied that the results of his observations are sufficient to determine the tidal curve at each place, at any time, when the known laws which govern the motions of the sea, the moon's phases, &c., are taken into consideration. This view is confirmed by the results of the self-registering tide gauge in the harbour of Friedrichstadt, on the Eider, by means of which tidal curves were constructed for fourteen consecutive days from the 13th of September, 1863. The observations were made in the vicinity of the following places:—Wyck, near the S.E. corner of the Island of Föhr; Ellbogen, at the N.E. corner of the Island of Sylt; Hörnum Odde, the southernmost point of the same island; Rothe Kliff, Westerland, and Gurt Flie, places on the western coast of Sylt; and Römo, an island to the north of Sylt: also at Amrum Odde, the northern point of the Island of Amrum, and at the southern point of the same island; at Osterlei, Westerlei, and Holländer Loch (three channels between Sylt and the mainland); and near the Islands of Nordstrand, Pelworm, and Habel.

The height of the water above a certain datum was registered at each of the above places every fifteen minutes for upwards of twelve hours consecutively, including thereby, in every case, at least one high and one low water. The work was commenced on the 18th of July, under favourable conditions, at a point about 1,100 yards north of Wyck, on the Island of Föhr. The water rose 7·87 feet, and afterwards fell 8·26 feet with the ebb. The duration of the rise was 5 h. 45 m., and of the fall 6 h. 45 m. Only three-quarters of an hour after high water the deeper current turned, as was shown by the swinging of the vessel, from which it may be concluded that the coast stream to the north during this period, at high tide, had overcome the effects of a powerful north wind.

The observations were continued on the 22nd of July at Ellbogen, on the Island of Sylt; and on the 28th in the Lister Deeps, where it was observed that high water stood unaltered for one hour. The Author gives a table of twenty-nine observations of velocities in the Lister Deeps, which were made with a log during ebb and flow, the measurements being taken at intervals of fifteen minutes. From these observations it appears that on the whole there was a greater velocity during the ebb than during the flow; and the

Author concludes that the quantity of water passing out through the Lister Deeps with the ebb is much greater than that which comes in with the flow of the tide.

The inquiry was now directed to the Island of Sylt, and especially to the tongue of land which joins the Island of Sylt proper with the Listerland. Measurements were made of this isthmus, and were compared with those given by the cadastral survey of 1840. This comparison showed a discrepancy of 8·2 feet in twenty-three years, from which the Author concludes that there can have been no important destruction of the west coast of Sylt, especially as it was found by similar measurements that no increase had taken place on the east coast.

On the 2nd of August tidal observations were continued at a point on the North Sea, 2,100 feet north of Rothe Kliff, in the Island of Sylt, under exceptionally favourable circumstances. It was three days after new moon, so that a strong tide was to be expected. Near this spot a clay bank was brought to light, which evidently ran out from the dunes. In the upper part, which was laid bare for a breadth of about 16½ feet, reed plants were found, and footprints of cattle. This bank was about 220 paces long, and dipped at each end under the slope of the beach. The mean height of the surface was 18 inches below the ordinary flood level of the inland sea. A section across the island of Sylt, at Gurt Flie, was taken by levelling, and simultaneous observations of the tidal curve were made on each side of the island. From these it was found that, owing to the difference of the times of high water on the two sides of the island, a difference of level of about 2 feet is produced, which causes a strong and regular scour from the inner West Sea round the Hörnum Odde, the south point of the island. The loss of land on the west coast of Sylt has been much exaggerated. Without going into details, it may be mentioned that the average yearly recession of the coast line for a length of about 5 miles, in front of the parish of Westerland, has been about 2·754 feet during the last twenty-nine years.

The loss of land here is not to be compared with that in the inner West Sea, where the Author has found the recession of the Hallyn and the S.W. coast to be 14 feet per annum on an average of fifty-six years. The actual loss of land is also shown on the well-known land maps of Dankworth's Geography, and is fully accounted for by the strong flood and ebb, in conjunction with the heavy breakers on the steep sides of the clay cliffs, whilst the coast line in Meier's chart of the year 1240, in front of Westerland, does not indicate any appreciable recession. The remains of the old church of Westerland, which was removed in 1825, are still to be seen on the coast of the dunes. The condition of the outer coast is not the same as that of the clay bank. The yearly surveys on the North Holland coast have clearly shown that the outer dune line since the year 1843 has receded very little, while the high-water line, on the contrary, has been thrown back by the accumulation of sand.

The breadth of the dune, on the boundary line between the villages of Westerland and Rantum, was 2,038 feet in 1834, and 2,216 feet in 1863, whereby the great accumulation of sand, and consequent extension of the dune, becomes apparent.

In the south of Westerland a clay bank came to light on the coast, similar to that already mentioned near Rothe Kliff. The surface of this bank has an inclination towards the sea of 1 in 12, and was exposed 16 feet in breadth for a length of 300 feet. The sea reaches the sand-covered foot of this bank every half flood. The surface is hard, and is furrowed in a remarkable manner. It appears to be a relic of the old sandstone ridges on the western headlands of Sylt, mentioned by the historian Kielholt in the fifteenth century. Similar indications of ferruginous clay and sandstone are seen on the coast of Jutland, opposite the Island of Fanö. From the 25th of August to the 1st of September, observations were made to the south of Sylt, in the inner West Sea, for determining the direction of the stream, from which it appeared that a coast stream, with a northerly direction, becomes very perceptible when the highest ford between Sylt and the mainland is immersed. Between the Fartrap Deeps and the Lister Deeps there is but a single waterway at high water between Sylt and the continent. A section was taken of this waterway from Morsum Nas in Sylt to the sea dike on the mainland near Klausebull Church. In this waterway three deep channels are found, one westerly under Sylt, one easterly near the continent, and one near the middle, called Holländer Loch.

The area of this waterway at ordinary flood-level was 14,400 square yards, and the length of the water line 12,600 yards, so that the mean depth was 3 feet 5·4 inches. A calculation of the quantity of water which ran through with the high-water current showed the large amount of 1,560 million cubic yards, flowing from the south, and not returning the same way; for the stream is null, or at most very weak, after the cessation of the high-water current from the south. The observations of the 28th of July showed that the ebb stream in the Lister Deeps was much stronger than the flood, and the continuous duration of high water there, already alluded to, is now satisfactorily explained.

A portion of the water conveyed by the high-water current may pass through the channel between the Island of Römo and the continent, but this cannot be large, because of the height of the ford at Römo. The Lister Deeps are the deepest of all the entrances to the Schleswig coast, and the best for navigation, and this is evidently due to the fact that the current is much greater at the ebb than at the flood. On the other hand, a conjecture may fairly be made that in the Fartrap Deeps the flood stream preponderates over the ebb, by which the quantity of water which flows into the inner West Sea considerably exceeds that which flows out by the same channel; and this will explain the bar foundations and periodical changes in the direction of the current at the entrance to these Deeps.

After tidal observations had been completed at Amrum, current measurements were undertaken, by which it was found that a high-water current ran between the Islands of Föhr and Amrum similar to that between Sylt and the mainland, already described. The greatest velocity of this current was 1·67 foot per second, and occurred thirty-eight minutes after high water, whereas the greatest velocity between Sylt and the mainland was 1·32 foot per second, and took place seven minutes after high water.

The Author groups the tidal curves on the Schleswig west coast into—Curves of the sea; curves of the deeps; and curves of the "Watten," or shallow places between the islands and the mainland.

As curves of the sea he includes those of Rothe Kliff, Westerland, Outer Gurt Flie, Hörnum Odde, and Amrum Odde.

As curves of the deeps, those of Pelworm, Habel, Hattstedt, Amrum south point, inner Gurt Flie, Wyck, and the elbows of List and Römo, which show remarkable peculiarities, as they lie more or less within the influence of the strong tidal developments of the sea.

As curves of the "Watten" he takes those of Osterlei, Westerlei, and Holländer Loch, near Sylt.

The Author remarks, in conclusion, that the form of the tidal curve in the North Sea, which he had taken near Nissum Fjord, on the coast of Jutland, did not agree with that obtained from observations near Sylt; but the rise of the tide at the former place is incomparably smaller, and low water continued for a much longer time. The advance of the tidal wave along the North Holland coast towards the mouth of the Elbe has also a great influence on the rise and fall of the sea on the west coast of Schleswig.

The Paper is illustrated by three plates containing all the tidal curves referred to in the text, and a map of the west coast of Schleswig, with sections across the Island of Sylt at Rothe Kliff and Gurt Flie, and a water section between the Island of Sylt and the mainland, from Morsum Nas to the sea dike.

B. T. M.

Cost of Cleansing the Streets of Paris.[1] By M. Vauthier.

(Annales industrielles, October 21 and November 4, 1877.)

M. Vauthier made a report to the Municipal Council on the extent, and the cost of maintaining and cleansing, the streets of Paris. The roads of Paris extend over a length of 558 miles, and

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. l., p. 223.

they cover an area equal to 3,523 acres, more than 18 per cent. of the total area of Paris within the fortifications:—

		Square yards.	Square yards.
	Paved roads	6,349,527	
	Macadamised roads	1,972,582	
	Asphalt roads	296,127	
			8,618,236
	Unmetalled roads (natural surface)		242,782
(53 per cent.)	Total area of the roads		8,861,018
(47 „)	Footpaths and blind alleys		6,691,636
	Total of all classes		15,552,654

The cost per year for maintenance and scavenging, exclusive of general charges, was for the first, second, and third roads above noted, as follows:—

	Maintenance. Per square yard.	Cleansing. Per square yard.	Total. Per square yard.
	d.	d.	d.
Stone pavement	4·50	3·37	7·87
Macadam	9·95	7·31	17·26
Asphalt	10·20	4·17	14·37

Here it is shown that asphalt costs nearly as much as macadam for maintenance and cleansing; and if the interest on the excess of original cost for asphalt above that for macadam, be added, the annual charge for asphalt will be greater than that for macadam.

The amount of special charges for urinals, watering, removal of snow and ice, &c., &c., is at the rate of $\frac{7}{8}$*d.* per square yard.

M. Vauthier discusses the merits and prospects of wood-pavement; and, as the result of an examination of the wood-pavements of London, he prefers Henson's pavement, now in Oxford Street.

D. K. C.

New Conduit for Water in the City of Florence.

(Giornale del Genio civile, An. xv., p. 405.)

This work, undertaken by the City of Florence at its own cost, and executed within a few months, is stated to be one of the most important of its class carried out in Italy for many years, both as regards the magnitude of the undertaking, and with respect to its technical and economical results. A full description of the details of the plan, by Commander Carrevari, the Engineer, is in course of preparation.

The object of the project, which at first encountered much opposition, was to collect by means of a "permeable gallery," or tunnel, excavated in the immediate neighbourhood of the city, the water which filters through the strata of pure sands and gravels that form the subsoil of the Arno valley. The water is conveyed into

basins, from which it is pumped up to supply the requirements of the city, the motive power being obtained from the fall of the Arno at the San Nicolo sluice, aided in time of drought by steam power. Large reservoirs have been established at a level sufficiently elevated to provide for delivery at any point of the city, and to regulate the supply of water to the canals.

Starting from the works situated on the site of the Old Mills, on the left bank of the Arno, the permeable tunnel ascends that bank as far as the Anconella ditch. It has been excavated to a depth of about 33 feet beneath the surface of the ground, and 21 feet below the low-water level of the Arno. It has a cross section of 58·5 square feet. It is lined with masonry, in which openings are left to allow the water to penetrate.

The works occupy an area of about 28,000 square feet. They are arranged in three storeys, of which two are subterranean. The lowest of these is occupied by the above-mentioned basins, from which the supply is derived for four pairs of pumps. Above these are the canals of intake and discharge for the water of the Arno, which, after having served as a motive power, passes through a walled canal, navigable for boats, along the Lung' Arno for 926 yards, and rejoins the river opposite the Loggie degli Uffizi. The storey above ground contains the machinery. There are two Girard turbines of an effective force of 340 HP.; also two Corliss steam engines, each of 70 HP., supplied with steam by four boilers, the united evaporative power of which is equal to 180 HP. Of the four pairs of pumps, three are calculated to throw 16·5 gallons of water per second each. The fourth pair, which is kept in reserve, is only equal to a supply of 8·8 gallons per second. The total power is thus equal to nearly 58·3 gallons per second, which can be discharged into the main supply pipes. This power of the machines is made to correspond to the supply of water obtainable from the permeable tunnel, which in the driest seasons has been found never to yield less than 55 gallons per second. In these periods of drought the services of the steam engines are required, in order to supply the deficiency in the motive power derived from the water of the Arno. The period for which they are employed is seldom more than two months.

The reservoirs are supplied from these works by a main laid under the Arno in a culvert beneath the San Nicolo sluice. The culvert is 765 feet long, and 21 feet under low-water surface-level. The main crosses the Piazza di Porta alla Croce, and runs under the streets Principe Eugenio and Principe Amadeo to the Piazza San Gallo. Here it bifurcates, one line leading to the reservoir of the Pellegrino, the other returning to the works by way of the Piazza Demidoff, whence a branch rises to the Carraia reservoir.

This principal artery of supply attains a length of 6¼ miles. The mains are of cast iron, of two sizes, the first portion measuring 32 inches in diameter, and weighing 82 lbs. per lineal yard; the second measuring 24 inches in diameter, and weighing 54·2 lbs. per lineal yard. Another pipe, of 16 inches diameter, and 2¾ miles

long, serves as a communication between the works and the ancient reservoir delle Quescie. Including the secondary pipes, of 20, 8, and 5·2 inches diameter, the pipage has a total length of more than 15 miles.

The reservoirs, placed at a height of about 115 feet above the general level of the city, are each divided into two large basins, separated by a central gallery, arched over and covered with a stratum of earth of from 3 to 4 feet thick. On the area thus formed are erected the sluice-houses, containing the sluices for the regulation of the water and dwelling-houses for the attendants. The Pellegrino reservoirs are 285 feet long and 66 feet wide, and able to contain 631,800 cubic feet of water. The Carraia reservoirs are square, and covered with small arches in brickwork, supported by stone piers. They will contain together 382,590 cubic feet of water.

The water collected in the permeable gallery is perfectly limpid. Chemical analysis has classed it with the waters of the Vergine and the Marcia supplies, which are so highly appreciated in Rome. Being raised to a height of from 100 to 115 feet above the general level of the city, the supply can be delivered at the top of the highest buildings, such as the Riccardi and Strozzi palaces.

The cost of the works is not yet completely ascertained, but approximately it may be stated at £268,000. The sum is considerable, as a burden on the finances of the Commune, but cannot be regarded as disproportionate for supplying the city of Florence with such a large quantity of excellent water. Compared with the estimates for other projects, the actual cost of the scheme of Commander Carrevari is the most economical. The estimate which most nearly approached it proposed to supply a quantity of 17·6 gallons per second, at a cost of £346,000.

F. R. C.

NOTE.—The population of Florence, according to the census of 1871, was 167,093 souls. The minimum supply of 55 gallons of water per second yields a ratio of 28·4 gallons per head per diem. The total cost of the works is about £1 12*s.* per inhabitant. The annual cost is not given; but as water is used as a motive power for more than three-quarters of the year, the total charge per head must be remarkably low. A rate of 3*d.* per head per annum would pay the interest on the capital and extinguish the debt in between twelve and thirteen years.—F. R. C.

Application of Water-Pressure Machinery to the New Water Supply at Sigmaringen Castle. By C. KRÖBER.

(Der Praktische Maschinenconstructeur, 1877, p. 395.)

The water supply of Sigmaringen Castle, the residence of Prince Charles Antony of Hohenzollern, was formerly obtained from a source on the left bank of the Danube by means of pumps driven by a water-wheel. Owing to the imperfect construction of the

machinery and the limited power, the water could not be raised to the upper storeys of the buildings. Improved machinery was therefore erected in October 1876, the Roman tower, situated about the centre of the castle, being chosen as the most convenient place for the reservoir.

The highest water level of this reservoir was 183·5 feet above that of the source, and about 203 feet above the Danube. The quantity of water required to be lifted per second was 0·408 gallon, and the total quantity of water supplied by the source 10·867 gallons per second; thus there remained for the motor $10·867 - 0·408 = 10·459$ gallons. The fall from the level of the source to the discharge of the proposed water motor was 13·1 feet. Taking the resistance of friction in the existing pressure pipe (of 4 inches diameter and 2,450 feet length) as equivalent to a loss of height of about 9·8 feet, the effective work to be done by the machinery was $0·408 \times 10 \times 193·3 = 788·6$ foot lbs.

The available water power $10·46 \times 10 \times 13·1 = 1370$ foot lbs. The machinery was therefore required to utilise $\frac{788·6}{1370} \times 100 = 57\frac{1}{2}$ per cent. of the available water power.

The application of a turbine with intermediate gearing would have occasioned a loss of effect amounting to at least 40 per cent.; a water-wheel would only have lost about 32 per cent. Adding to this a loss of effect of 15 per cent. by the pumps, the effect of the whole machinery was estimated at 55 per cent. These considerations induced the engineer to use direct-acting water-pressure machines, and although these had probably not yet been applied for so small a head of water (13 feet), no doubt was entertained as to their superiority over turbines or water-wheels. Experiments on the loss of effect arising from friction of the pistons and from other sources, were made by Messrs. Sulzer Brothers, and the result justified them in undertaking the construction of the machines under guarantee to lift 0·408 gallon of water per second into the high level reservoir with the available water power.

To enable repairs being made without a complete interruption of the water supply, the machinery was constructed in duplicate. The machines were arranged horizontally, the pumps were single-acting plunger pumps, the piston rods of the motor serving as plungers of the pumps. By attaching the pump cylinders immediately to the covers of the central or pressure cylinder, only one stuffing box was required on each side of the motor to separate the two water spaces.

The starting of the machinery completely justified the expectations of the engineer. The measurements and experiments made by him showed, that for the normal work it was necessary to throttle the headwater, and that the required quantity of 0·408 gallons could be pumped into the reservoir by 9·8 gallons of water at a pressure corresponding to a height of 10·66 feet. Taking again

the resistance of friction in the tubes as equivalent to a loss of height of 9·8 feet, the machines utilise $\frac{0 \cdot 408 \times 193 \cdot 3}{9 \cdot 8 \times 10 \cdot 66} \times 100 = 75$ per cent. of the consumed water power.

The indicator diagrams taken from the pumps as well as from the pressure cylinder, showed a perfect uniformity of pressure. The pressure pistons have 1 foot $3\frac{1}{9}$ inches, and the pump pistons $3\frac{1}{4}$ inches diameter. The stroke is 3·3 feet.

A. H.

On the Value of Falls of Water. By A. CANTALUPI.

(Il Politecnico, An. xxv., p. 738.)

Signor Cantalupi remarks that the economical value of a fall of water of a given dynamical power is as yet undetermined; the treatises on the money value of water being confined to the subject of its use in irrigation. In cases where estimates have been offered of the supply of water-power to be afforded by canals, they have been variously priced at £8, £12, or £16 for every dynamical HP., without any attempt at proof. A dynamical HP., according to the Italian scale, is the power corresponding to lifting a weight of 75 kilogrammes to a height of 1 mètre in one second. This is equal to 75 × 7·233 foot-pounds, = 542·5 foot-pounds of work per second, which is 1·37 per cent. less than the English value of a HP., namely, 550 foot-pounds of work per second. Omitting any notice of the variation in quantity, from time to time, in a fall of water, Signor Cantalupi regards the mean HP. alone. To obtain a dynamical HP. from a condensing steam engine, expansively worked, 3·20 kilogrammes of coal (= 7·04 lbs.) per HP. per hour are said to be required; which gives 32 kilogrammes (70·4 lbs.) in ten hours. The price of coal is rated at 6 lire per quintal, or about 2*s.* 4*d.* per cwt. Working for three hundred days in the year would thus involve the expenditure of 576 lire, or £23·04, corresponding to the employment, at 5 per cent., of a capital of 10,920 lire, or £436·8. Signor Cantalupi is of opinion that it would be altogether inadmissible to set down such a figure as the value of a dynamical HP. obtained from a fall of water. He considers that a true comparison is to be made according to the facility afforded to human work in any given locality. Thus he cites the case of a mill, which may be let at a rent of £20 for each pair of stones. For two pairs of stones the rent would thus be £40 per annum; a sum which cost of repairs and alterations would reduce to £32. Capitalising this rent, the sum of £640 is obtained. The cost of the mill is estimated at £240, and that of the machinery at £96. Thus the total capital expended is £336. But the rent of the mill corresponded to the interest on a capital of £640. The difference between these two sums, or £304, is thus the value of the water

power; as that is taken at 8 HP. it is worth £34 per HP. This mode of valuation gives results of various amounts, corresponding to the localities of the water falls; which Signor Cantalupi considers to be the true mode of ascertaining their proper value.

F. R. C.

The Theory and Construction of Turbines. By PROFESSOR C. FINK.

(Verhandlungen des Vereins zur Beförderung des Gewerbfleisses, 1877, pp. 192–249.)

The experiments of the Author have extended over a period of more than thirty years, first with the Fourneyron turbine, the only one then known, and later with the Jonval and others. In some general remarks attention is drawn, by means of diagrams, to the influence which the thickness of the blades has upon the useful effect of the wheels; a uniform thickness giving, in consequence of the variation of the angle which the blade makes with the wheel rim, a cell or waterway which contracts the more as the angle deviates more from 90°. Without attaching much importance to this fact at the present stage of the inquiry, it proves to be a general defect which in some cases it may be desirable to obviate.

Turbines may be divided into axial and radial turbines, each class being again subdivided into pressure turbines and reaction turbines.

Taking axial turbines into consideration first, in which category those of Henschel and Jonval are comprised, an extensive series of complicated formulæ is evolved, by the aid of which the practical construction of this class of turbines is determined, data derived from actual experience supplying the numerical values and forming the fundamental basis for other considerations. No calculation of the frictional resistances is attempted, as from its involved and complicated nature it can only have a theoretical interest; these are estimated empirically.

In practice the useful effect is taken as a basis. The smaller the loss of axial velocity, the greater must be the sectional area of the turbine, and its attendant loss of power. With the sectional area increases the weight of the structure, and with both the pressure on the footstep. At the same time the loss of water at the joint is augmented in a direct proportion; and finally with the weight the price also. The number and thickness of the guide blades and driving-wheel buckets, the height of the guide and driving wheels, the form of the buckets, the proportion of the outer to the inner diameter, the diameter itself, the variable velocities and the displacement of the particles of water, and also the unavoidable shocks of the water entering the driving wheel from the guide wheel, are matters of great importance.

The sum of the hydraulic resistances may be taken at 15 per cent. of the fall or head H, which, with $6\frac{1}{4}$ per cent. and $3\frac{3}{4}$ per cent. for

non-utilised velocity of the water, and for friction on the footstep respectively, leaves a useful effect of 75 per cent. of the available head of water, an effect which may be obtained under the most favourable circumstances. On the angle β, which the bucket forms with the surface of the wheel where the water enters, depends whether the turbine is to act by pressure or by reaction; the latter is generally preferred. For pressure turbines the angle α, which the guide blade makes with the horizontal or the under surface of the fixed guide wheel, is 14° 30′ if the axial velocity of the water is, as it may be, taken as $0 \cdot 2305 \sqrt{2\,g\,H}$; hence $\beta = 27° 20'$. These angles correspond to the mean radius; for the extreme radius their cotangents are to be multiplied with the proportion of the radii $\frac{10}{8 \cdot 5}$, and this results in $\alpha = 12° 20'$, $\beta = 23° 45'$. For reaction turbines the angles on the mean radius are $\beta = 90°$, $\alpha = 20°$, and for the outer radius $\beta = 90°$, and $\alpha = 17° 10'$. If the proportion of the radii is taken as $r = 0 \cdot 7\,R$, and R so large that ten times the quantity of water may flow through its area with the velocity due to its head, the result is $R = 0 \cdot 85 \sqrt{\frac{Q}{\sqrt{H}}}$, Q being the product of the velocity of the water into the sectional area of the buckets, or what is the same: the quantity of water passing through the machine.

The form of the bucket is determined by three factors; the angles α and β and the depth of the wheel. The smaller the depth of the wheel, the larger must be the number of buckets, and *vice versâ*, but narrow cells or buckets are more liable to get choked up; and it follows that, for small turbines, the number of buckets should be less than for large ones; in other words, the proportion of the depth to the diameter should not be constant. The Author never gave more than twelve buckets to the smallest, of about 15·8 inches (0·40 mètre) diameter, and thirty-six to the largest, of 11·8 feet (3·6 mètres) diameter. He assumed that the number of buckets varies as the square root of the diameters; and if D = diameter in mètres, and N the number of buckets (or cells), $N = 18 \sqrt{D}$, or $20 \sqrt{D}$; and for pressure turbines, in which the cells are usually nearly double the width, $N^1 = 30 \sqrt{D}$. The guide blades, which have the function of delivering the water into the driving wheel under a proper angle, need not be very numerous for that purpose. The Author has made wheels with ten and twelve blades; but this plan has the disadvantage that the driving-wheel cells become narrower than those of the guide wheel, and when choking occurs, it generally first takes place in the more inaccessible driving-wheel cell. Hence it is advisable to choose the number of guide cells so that they are equal in width, or narrower, than the wheel cells; and if $\beta = 90°$, the number of guide cells = N, or for $\beta = 90° + \alpha$, $= 1 \cdot 1\,N$; for pressure turbines they may be taken as $= 0 \cdot 6\,N$.

The Author then gives the formulæ for the several values of the depth of the wheel (e) for radial and for pressure turbines.

For *internal pressure turbines*, the limit of useful practical re-

tardation of the velocity of the water may be taken as before, viz., $0 \cdot 2 \sqrt{2gH}$, or $0 \cdot 25 \sqrt{2gH}$, which implies a loss of power of from 4 to $6\frac{1}{4}$ per cent.; add to this 2 per cent. for friction in the steps, and it will make from 6 to $8\frac{1}{4}$ per cent. loss of power. Hydraulic resistances may be taken at 20 per cent. The sectional egress area of the water $= \frac{5 \cdot 11\, Q}{\sqrt{2gH}}$, and the ingress area $\frac{R}{r} \cdot \frac{5 \cdot 11\, Q}{\sqrt{2gH}}$. The proportion $\frac{r}{R}$, or $\frac{R}{r}$, can only be fixed upon practical considerations (R is the outer and r the inner radius of the driving wheel). For inward-flow turbines, the ratio $\frac{R}{r} = 1 \cdot 4$ has answered well; for internal ones it would appear equally well adapted, but it seems desirable to increase it to $1 \cdot 5$ for small ones, and to reduce it to $1 \cdot 25$ for larger ones. The internal radius r may be taken $= 1 \cdot 78 \sqrt{\frac{Q}{\sqrt{2gH}}}$, and the depth $e = 0 \cdot 182\, r$, and the diameter of the supply pipe $= 2 \cdot 84 \sqrt{\frac{Q}{\sqrt{2gH}}}$, which requires a velocity of water $= \frac{\sqrt{2gH}}{6 \cdot 4}$, or about 1 mètre for a head of 2 mètres. If with great heads long lines of pipes are employed, it is advisable to choose the pipes larger, and to decrease them gradually to their proper diameter before joining the machine.

The angles α and β, the number of buckets, and the form of the guide blades are also discussed.

Internal Reaction Turbines.—As the angle β becomes now 90°, the angle α is varied also, and with it the number of buckets or cells. The value of α becomes 29° 20′; that of $S = 2 \cdot 99 \sqrt{\frac{2gH\sqrt{2gH}}{Q}}$ and that of $n = 25$ to 30, being the number of revolutions of the wheel, and the number of cells in the driving wheel, respectively. If the net cross section of the guide cells is not to exceed that of the driving-wheel cells $n^1 = \frac{4}{3}\, n$, *i.e.* 34 to 40, the shape of the guide blades is found as in the pressure turbines.

After dealing with external pressure and external reaction turbines, the Author states, in conclusion, that the inward-flow turbines must be considered as giving a greater useful effect than the outward-flow turbines; they are also superior on practical considerations. Their diameter is about $\frac{1}{7}$ less than internal wheels, and the hydraulic resistances and loss of water from the joint are also less. Further, inward-flow turbines have fewer buckets; they are shorter and have less curve; the egress velocity of the water being as 608 to 384 and 841 to 507, for inward and outward flow pressure, and reaction turbines, respectively. Another characteristic of inward-flow turbines is that they use less water when running more quickly than their normal speed,

whereas the outward-flow ones use more. In this lies the explanation that, within somewhat large limits of variation of normal speed, the useful effect of the former is not materially altered, as is shown by the following numbers, which the Author obtained from a series of dynamometrical tests :—

Revolutions.	HP.	Revolutions.	HP.
40	17·08	43½	31·17
45	18·11	50	33·26
48	18·02	55½	34·15
51	17·85	60½	34·16
53½	17·33	65	33·47
57	17·16	69	31·97

Regulation or partial throttling is best effected by turning movable blades.

A. H.

The Theory and Construction of Centrifugal Pumps.

By Professor C. Fink.

(Verhandlungen des Vereins zur Beförderung des Gewerbfleisses, 1877, p. 350.)

With few modifications the fundamental laws for the construction of turbines, are also applicable to centrifugal pumps. Although they are more wasteful of motive power than piston or plunger pumps, they are often preferred for their simplicity and inexpensiveness.

If water is to be compelled by the rotation of a vane to overcome the pressure of a lift or head and to make an upward movement, it is necessary to give such a rotary velocity to the wheel that the pressure due to the centrifugal force in the body of water that is made to rotate with it is greater than the pressure due to the lift or head. This principle results in the centrifugal pump proper; another class—constructed after the manner of axial turbines—is that of rotary pumps.

Centrifugal pumps are constructed in two ways: with parallel casings and with converging casings; and, again, in some cases they are concentric, and in others the external discharge chamber takes the form of a spiral with or without guide blades. The Author bases the consideration of the subject mainly upon the formulæ developed for turbines, and institutes the necessary modifications.

H = head of water, the pressure of which equals the pressure due to the centrifugal force at a certain velocity.
R = the external diameter of the pump disk.
r = the internal diameter of the driving wheel.
λ = the height or thickness of the wheel.
Q = the angle formed by the radii touching the ends of the vane.
q = the quantity or volume of water to be raised per second.
d = the diameter of the suction and discharge pipes.

v_1 = the velocity of the periphery of the circle of which r is the radius.

c_1 = the radial component of the velocity with which the water enters the wheel at r.

In the construction of centrifugal pumps, if a certain quantity of water had to be lifted to a height H, and this was effected with a certain number of revolutions, and it was then desired to lift the same quantity to the height H^1, the number of revolutions of the pump was altered in the ratio of $\sqrt{H}$ to $\sqrt{H^1}$. This has the disadvantage that it increases not only the velocity of the water in the pipes but also the quantity raised at the same time, and it follows that for a greater lift and the same quantity the pumps must be made smaller. By this, however the number of revolutions is further increased, and the velocity of the water in the pipes with it, so that the greatest possible lift may be determined beyond which the effect of the pump would be lessened. This circumstance raises the question whether it be not possible to fix a limit of velocity of the water in the pipes, as in the case of plunger pumps, beyond which centrifugal pumps should not be run; the frictional resistances would thereby be lessened, greater lifts could be attained, and the useful effect generally increased. This can be done, because there is no doubt that the suction and pressure pipes can be taken as large as in ordinary pumps; it appears doubtful, however, whether the construction of the pump can be based on a constant ingress velocity of the water, but even this is possible if the radial thickness of the pump rim $(R-r)$ is made a function of the lift and is not taken as hitherto—constant. The greatest possible lift =

$$\frac{v_1^2}{2g} \cdot \frac{R^2 - r^2}{r^2};$$

hence it will be seen that it increases not only with the square of the velocity v_1, but also with the difference of the squares of the radii. Taking 1 mètre as the minimum velocity of the water in the pipes, and $1\frac{1}{2}$ mètre as the maximum (a practical consideration to limit the number of patterns and sizes of pumps for a certain range of lifts), the diameter of the pipes is determined as follows:—

$$d = 1 \cdot 13 \sqrt{q}.$$

Also
$$r = \tfrac{1}{2} d = 0 \cdot 564 \sqrt{q};$$
$$\lambda = \frac{25}{72} r;$$

and
$$c_1 = 1 \cdot 7 \text{ mètre}.$$

v and $\frac{R}{r}$ can only be determined, in the absence of experimental data, by assuming certain proportions, based on practical results, as the most advantageous. Supposing, thus, that $\frac{R}{r} = 2$, and the lift

is 4 mètres with a velocity of water in the pipes of 1 mètre, then the same pumps may be used to raise $1\frac{1}{2}$ time the quantity of water 9 mètres high with a velocity of $1\frac{1}{2}$ mètre, being a lift of $1\frac{1}{2}^2$ that of the previous one of 4 mètres;

$$v_1 = 5 \cdot 11 \text{ mètre};$$

from these proportions tables are constructed giving the values of $\frac{R}{r}$, the lift in mètres and the values of the angle Q.

A. H.

On the Ventilation of Millstones in Flour Mills.

By H. Fischer.

(Dingler's Polytechnisches Journal, vol. ccxxv., p. 427.)

On the first introduction of the system of creating a draught of air between the millstones, for the purpose of cooling the flour, pressure fans were used, but these were abandoned on account of the amount of fine dust forced into the mill; at present exhaust fans are alone employed. The original method of connecting the exhaust fan with the different pairs of stones, was to have branch pipes leading from the casing of each pair into a common collecting pipe, and thence through the fan into a dust chamber. The objection to this arrangement was that the air took up moisture from the damp grain, which, being condensed on the cold sides of the air passages, formed a paste with the fine dust from the flour. In the course of time this paste became decomposed, and an inflammable gas was disengaged which occasionally took fire and spread through the air trunks all over the mill. In 1868 the Author completed a system of ventilation which was intended to overcome the objections to the previous system. The principal improvement consisted in making the air pipes double, the outside being wood and the inside metal, an air space being left between them; these pipes were non-conductors of heat, and much of the condensation was thus avoided. The system of Jaacks and Behrns, however, introduced in the same year, has since proved greatly superior to all others.

A sieve of woollen twill is introduced into the top of the casing of the stones. This sieve is stretched over a system of rods placed zig-zag, in such a manner as to expose a large amount of surface; the suction pipe is taken from above the sieve, so that all the particles of flour dust are filtered out of the air, preventing deposit in the pipes and doing away with the dust chamber. The framework of the sieve is not rigidly connected to the case; it also carries a stud which projects through the casing, and about every hour the miller has to strike the stud with a hammer to shake off the dust and free the pores, having previously closed the throttle-valve of the air pipe so as to allow the dust to fall away from the sieve.

In the present Paper the Author describes, with the aid of diagrams, a few mechanical means for periodically shutting the air off and striking the stud. The first apparatus is that manufactured by G. Luther, of Brunswick. The throttle-valve is closed by a cam on a shaft releasing a weight, another cam then causes the hammer to fall, and a tumbling weight opens the valve again. The second arrangement is that of Jaacks and Behrns, the inventors of the system, the distinctive feature being that their gear is driven by a ratchet and pawl instead of a belt. The third plan is a later one of Luther, in which the motion for tripping the hammer is obtained from a small crank disk driven by a belt. The last plan, by Schmeisser and Sultz, of Neustadt, is very similar to the first one of Luther, but has a simple arrangement of elastic cords for closing and opening the valve. The principal object to be attained is to close the valve just before the hammer strikes, and to open it immediately afterwards so as to check the draught for as short a time as possible.

W. P.

The Horizontal Otto-Langen Gas Engine. By H. Wacker.

(Journal für Gasbeleuchtung, vol. xx., p. 474.)

Gas engines, although well adapted to small branches of manufacture, have made comparatively little progress, in consequence of their imperfections. Lenoir's and Langen's (the earlier) systems are those mostly used in Germany; of the latter about 4,500 engines being in operation. They are cheaper and handier than Lenoir's, which require about four times as much gas; its great noisiness and excessive wear and tear have also much restricted its use.

These defects have now been overcome by Herr Otto, the joint inventor. The new engine is a single-acting high-pressure one. The construction resembles a horizontal steam engine. The main improvement consists in compressing the mixture of gas and air previous to ignition; and while a portion of the gases is kept back in the cylinder, the process of combustion is thereby somewhat retarded. The proportions are about the same as in the earlier engine, viz., 11 parts of atmospheric air to 1 part of gas. The cylinder is surrounded by a cooling jacket, to prevent heating.

The *modus operandi* is as follows: The fly-wheel is placed in such a position that the piston after having passed the centre makes one full stroke. This is the proper moment for opening the gas tap, and lighting and regulating both flames. After another turn or two of the fly-wheel the engine begins to exert its power, and this rises rapidly until a steady motion is obtained. The slide-valve, which is driven direct from the crank-shaft, admits the air to the gas, ignites the gases and shuts them off, all simultaneously. In comparison with the earlier engine all the parts of the new one are more accessible, the greasing is easier, and the working

more certain; the attention required is very slight. The piston is solid, the packing being effected by steel rings; the average speed is 180 revolutions per minute, and with this the wear and tear has, as yet, been very moderate. All the previous noise is now entirely obviated, with the exception of the aspiration and expiration of the gases.

It has been urged as an objection against gas engines, that they injure the mains and cause disturbances in the supply. This is not the case, however, since in many towns of the size of Leipzig as many as sixty of the early imperfect engines have been at work without causing any inconvenience. Where the supply pipes are too small the aspiration of the gas in the engine has, no doubt, caused flickering in the neighbouring lights; but this can be remedied, either by laying down a larger pipe or inserting one or two india-rubber bags.

Oil gas has likewise been employed successfully as a motive power for these engines, although some modifications in the details had to be made.

A pressure in the mains of from 0·709 to 0·984 inch suffices, and at Carlsruhe there are at present twenty-two of the Otto-Langen engines, from 1 to 4 HP., at work, with a pressure of only 0·669 inch. Wet meters are not advisable, whereas the dry ones have given good results. The consumption of gas varies from 27 to 30 cubic feet per HP. per hour.

J. G. H.

On the Temperatures observed in the Sperenberg Borehole.

By F. Henrich.

(Zeitschrift für das Berg-, Hütten- und Salinen-Wesen, vol. xxv., p. 58.)

The absence of springs in the salt strata, and the protection of the thermometer from currents in the water column, by means of india-rubber covers, are certain reasons why the temperatures observed in a series of carefully-conducted experiments in the above bore-hole, may be considered as the most reliable hitherto ascertained at such great depths; the reduction in temperature of the water, caused by the solution of rock salt, is not considered as an element affecting the observations, as the isolated part of the water column, *i.e.*, between the india-rubber covers would, after saturation, slowly regain the temperature of the strata.

The result of these observations was to show that the temperature increased at a comparatively uniform rate of 1·8° Fahr. for every 100 feet.

The special object of the Author is to point out and explain the apparent errors in a formula and resulting calculations previously adapted to the above observations by Herr Dunker, but the article possesses an independent interest, inasmuch as a formula is intro-

duced which is more consistent with the increase of temperature as actually observed, the comparisons being shown in a tabulated form.

The formula adopted by Herr Dunker certainly showed an increase of temperature throughout the range of the hole, and if further worked out, to a depth of 5,162 feet, but beyond this a decrease is shown, the zero point being passed at a depth of 10,874 feet; this anomalous result is attributed to the introduction of the mean temperature at surface as a constant in the formula, an error which is afterwards alluded to.

After mentioning that if the depths and temperatures, within the range of the observations, be taken, respectively, as abscissæ and ordinates, the result is a straight line instead of a parabolic curve, it is stated that the law of increase must be determined by the equation $T = m\ D + n$; D being the depth and T its corresponding temperature, while m and n are two constants arrived at from the following values:

$$\Sigma\ (T) = 8n + m\Sigma\ (D)$$
$$\Sigma\ (D \times T) = n\Sigma\ (D) \times m\Sigma\ (D^2);$$

Σ being the known sum of the series and the observations eight in number.

The formula is therefore $T = D \times \cdot 0175338 + 58 \cdot 61239$.

TABLE.

Depth in Feet.	Actual Temperature (Fahrenheit).	Calculated Temperature (Fahrenheit).	Difference between Actual and Calculated Temperature.	Actual Increase for 200 feet.	Calculated Increase for 200 feet.
700	70·869	70·887	+ 0·018	..	..
900	74·255	74·392	+ 0·137	3·386	3·505
1,100	79·581	77·900	− 1·681	5·326	3·506
1,300	80·397	81·408	+ 1·011	0·816	3·506
1,500	84·375	84·913	+ 0·538	3·976	3·505
1,700	87·667	88·421	+ 0·754	3·292	3·506
1,900	91·634	91·926	+ 0·130	3·967	3·505
2,100	96·503	95·434	− 1·091	4·869	3·506

After comparing the results of this table with those of Herr Dunker, and stating that the probable constant error is reckoned to amount to ·6716°, the writer frames a second table, varying from the preceding only inasmuch as another observation, taken at a depth of 3,399 feet, alters the constants. This last reading, which amounted to 115·875° Fahr. was omitted in the first table, on the supposition that the series of observations at regular distances could not be accurately obtained. Taking this ultimate reading, however, and continuing the scale of ordinates and abscissæ, it will be found that the straight line is continued and the

results of the table do not vary materially from the first, the calculated increase of temperature being 3·352° for every 200 feet as compared with 3·506°.

An explanation is then entered into respecting the nature of the constant (58·612°), which is considerably more than the mean temperature at the surface (48·15°). When the readings were commenced, the borehole had already attained a depth of 1,520 feet, and it was then found that at a depth of 50 feet, the temperature, after protecting the thermometer, was 6° above the mean at surface; this was ascribed to the conductive power of the tubes, as well as to the circulation of water between the tubes, of which there were three sets in the upper part of hole, but these are not necessarily the causes.

In a standing column of water, free from springs, and not overflowing at the surface, the currents which exist must ultimately tend to equalise the temperature of the strata; thus, at a depth of 3,390 feet, the temperature of the water column was 107·6°, while, after isolation, by means of the covers, it was found to be 114·35°. It is therefore evident that, after the lapse of a certain time, the strata at the bottom must lose a portion of its natural temperature, while that at the top will, on the contrary, become warmer, there being a neutral point between the two where the column is of same temperature as the rock. The actual effect of such a water column remains to be determined; but the constant depends upon the relative differences of the rock as altered by the current, and will be the more removed from the mean temperature as the differences become greater; thus, if on a renewal of observations in the Sperenberg borehole, it were found that the top strata had become warmer and the bottom strata cooler, by the continued action of the currents, then, the neutral point remaining the same, the constant (58·612°) would be greater, although most probably the increase would work out uniformly. If, however, the neutral point varies, the scale of increase might show some curve such as belongs to the equation,

$$T = a + b\,D - c\,D^2 + d\,D^3.$$

Some remarks are made on the impossibility of arriving at absolutely correct readings, even in the case of taking observations immediately after the boring tools are withdrawn; allowing that the warmth developed by the act of boring is either ascertained or is common to all observations, so that an equal scale would result, it is evident that, during the time necessary to obtain a reading, the column of water standing on the isolated part between the covers would, taking the case of considerable depth, absorb some of the warmth from the latter.

A. S.

Increase of Temperature in the Maria Mine.

(Zeitschrift für das Berg-, Hütten- und Salinen-Wesen, vol. xxv., p. 241.)

At the Maria Mine, near Aachen, the following observations have been made from time to time as deeper levels were reached. The datum line is 585½ feet above sea level.

Depth in Feet.	Temperature (Fahrenheit).	Temperature of Mine Air.	Temperature at Surface.
820	59·36	62·6	55·76
1,017	62·78	64·4	
1,213	66·47	62·6	
1,607	70·88	69·8	
1,844	75·56	78·8	

The temperatures were ascertained by means of a differential thermometer, placed in holes at each of the respective levels, the holes being about 3 feet 3 inches deep, filled with water, and afterwards made air-tight.

A. S.

Tests for Dynamite Detonators. By P. Hess.

(Mittheilungen über Gegenstände des Artillerie- und Genie-Wesens, 1877, pp. 387–393.)

The Author calls the attention of users of dynamite to the necessity of employing detonators of sufficient strength to produce complete explosion. He suggests the adoption of some ready and reliable test whereby the quality of a detonator may be quickly ascertained, and points out one which he asserts to be of the character required. A measurement of the charge contained in a detonator cap can afford no indication of its strength, since it may vary greatly in chemical composition. It is well known that some caps, containing a charge of 15 grains, fail to explode a frozen primer cartridge, although other caps containing only 4·5 grains may succeed. This may be caused by: 1. Impurity of the fulminate of mercury. 2. The chlorate of potash with which it is mixed may be in excess. 3. The quantity of gum used to bind the charge and to protect it from moisture may be too great; or a large proportion of moisture may be present. The chlorate of potash serves not only to bind the grains of fulminate together, but, if added in certain proportions, to increase the effect of the charge. These proportions are shown in the following equation—

$$3\,C_2N_2O_2Hg + 2\,KClO_3 = 6\,CO_2 + 6\,N + 3\,Hg + 3\,KCl.$$

The proportions are 77·66 per cent. of fulminate, and 22·34 of

chlorate; and if these are adopted in the preparation of the composition, the maximum detonating effect is obtained. The Author, in conjunction with some other members of the Austrian Military Committee, carried out a series of experiments with detonators manufactured by two different firms. The first tried contained a charge of 0·5 gramme of fulminate of mercury, and were classed for reference as A detonators; the others contained 0·3 gramme of fulminate of mercury and chlorate of potash, in nearly the proportions indicated by the foregoing formula, and these were distinguished as B detonators. Chemical analysis showed that the fulminate of the A detonators contained a large proportion of free mercury, while that of the B detonators was very pure. The experiments were first made upon primer cartridges in the frozen state. Of ten attempts to produce detonation in the frozen cartridges, with the A detonators, seven only were successful. Subsequently three other attempts were made, two of which ended in failure. The experiments were continued with the B detonators; and as perfect detonation was produced eight times in succession, the results were considered sufficient. Experiments were then made to ascertain the effect of these detonators upon a piece of sheet-iron ·029 inch thick, with the object of discovering a convenient test of quality. A sample piece of the iron was first put into a vice, and bent backwards and forwards to a right angle till it broke, the fracture occurring between the fifth and the sixth bending. The cap was laid upon the plate at a distance of about $2\frac{3}{4}$ inches from the edge, and bound to it with string. The plate was then laid upon the ground where the surface was free from stones, and the cap fired with the following results:—

1. In six experiments with the A detonators, the plate was ruptured twice and slightly indented four times.
2. In six experiments with the B detonators, the plate was ruptured six times.

It was thus shown that the B composition was greatly superior to the A charges of impure fulminate. But attention is here mainly directed to the discovery of a measure of effect sufficiently accurate for practical purposes. For it is evident that, to ensure the detonation of dynamite under all conditions, the detonator used must be capable of rupturing, when disposed in the manner described, an iron plate ·029 inch thick.

G. G. A.

On the Specific Heats of Vapours. By E. Wiedemann.

(Annalen der Physik und Chemie, new series, vol. ii., p. 195.)

The Author wishes to ascertain if there is not some connection between the specific heats of substances in their fluid and gaseous states. In describing Regnault's method for determining the values of the specific heat of various vapours, which consists in

superheating the vapours to temperatures (t_0° and t_1°) as far apart as possible, and observing the amounts of heat (Q and Q_1) given forth in each case in condensing, and by the difference of the two obtaining the specific heat, thus:

$$Q_1 - Q = C\,(t_1 - t);$$

so that a small error in one of the quantities Q or Q_1 introduces a large one in their difference $Q_1 - Q$, and consequently in C.

The Author's method, which, with the observations, is described in full detail, consists in observing the amount of heat given forth by the vapour in cooling from one temperature to another, both being above the boiling point of its liquid, thus making the method more exact. He obtains the following results for the substances he experimented on, which closely agree with Regnault's results at the same temperature:—

For chloroform	$C_t = 0{\cdot}1341 + 0{\cdot}0001354\,t$
„ ethyl-bromide	$0{\cdot}1354 + 0{\cdot}0003560\,t$
„ benzine	$0{\cdot}2237 + 0{\cdot}0000228\,t$
„ acetic acid	$0{\cdot}2984 + 0{\cdot}0007738\,t$
„ acetic ether	$0{\cdot}2738 + 0{\cdot}0008700\,t$
„ ether	$0{\cdot}3725 + 0{\cdot}0008536\,t$

C_t being the co-efficient of specific heat at the temperature t° centigrade.

He then compares these results with those of their respective fluids, and finds that with any temperature the specific heat of the vapour corresponds with that of the fluid; and that the alterations of the specific heat of fluids and their vapours are of the same magnitude. The comparison also seems to show that as there are more atoms in a molecule, so the specific heat is greater; and that these alterations may be attributed to the effect of internal work being done on the molecules.

F. J.

The Liquefaction of Gases.

The following is a *résumé* of the contents of several articles that have appeared in the "Comptes rendus de l'Académie des Sciences," descriptive of the important work and discoveries of M. Cailletet and of M. Pictet as regards the liquefaction of gases and of atmospheric air. M. Cailletet first draws attention [1] to the liquefaction of acetylene. This gas departs from Mariotte's law under high pressures, and it was successfully liquefied in an apparatus which is the type of that subsequently employed for the liquefaction of more intractable gases. This apparatus consists of a hollow steel cylinder, a kind of inverted test-tube, the sides of which are very thick, in order to resist the pressure of several

[1] "Comptes rendus de l'Académie des Sciences," vol. lxxxv., p. 851.

hundred atmospheres. The upper part of this cylinder carries a glass reservoir containing the gas to be liquefied. This reservoir is formed of a thick glass tube of small diameter, fused into a larger tube immersed in mercury, with which the hollow cylinder is filled. The test-tube is thus submitted to equal pressures within and without, and this admits of its taking larger dimensions in spite of the high pressures employed. The gas is compressed by means of a hydraulic pump, with the intervention of a layer of mercury. Acetylene liquefies under the following pressures: at $+1°$ C., under 48 atmospheres; at 10° C., under 63 atmospheres; and at 31° C., under 103 atmospheres. M. Cailletet here points out that the apparatus he has devised may be used for the liquefaction of a large number of gases. Shortly after this communication to the Academy, M. Berthelot presented a note[1] from M. Cailletet, stating that nitrogen binoxide had been liquefied under a pressure of 104 atmospheres at a temperature of $-11°$ C. At $+8°$, this gas maintained its gaseous condition under a pressure of 270 atmospheres. Quickly following, appeared another note from M. Cailletet, announcing the condensation of oxygen and of oxide of carbon. It was found that oxygen and oxide of carbon maintained a gaseous condition at $-29°$, and under a pressure of 300 atmospheres; but suddenly allowed to expand, the intense cold produced by this expansion caused the formation of a thick mist, due to the liquefaction and perhaps to the solidification of the gases. This phenomenon has also been observed when carbonic acid and nitrogen dioxide have been released from powerful pressure. Almost contemporaneously with M. Cailletet's announcement, a telegram was received from M. Raoul Pictet, of Geneva, informing the Academy that he had succeeded in liquefying oxygen under a pressure of 320 atmospheres, and at $-140°$. The method employed by M. Pictet consisted in the use of sulphurous acid to liquefy carbonic acid, this being utilised in the cooling of the oxygen gas, which finally liquefies on the pressure of 320 atmospheres to which it has been subjected being removed. The method of M. Cailletet, and that of M. Pictet are therefore essentially different.

Subsequently, M. Cailletet[2] announces the liquefaction of hydrogen and of atmospheric air by the apparatus employed in the liquefaction of the other gases.

M. Dumas[3] considering oxygen as belonging to the sulphur group, and isomorphous substances as having the same atomic volume, had concluded that the atomic volume of sulphur being $\frac{32}{2}$, that of oxygen would be $\frac{16}{1}$, and reciprocally that the density of liquid or solid oxygen would be $\frac{16}{16}$, or the density of water. M. Pictet, from the space occupied in his apparatus by the liquid

[1] "Comptes rendus de l'Académie des Sciences," vol. lxxxv., p. 1017.
[2] *Ibid.*, vol. lxxxv., p. 1270.
[3] *Ibid.*, vol. lxxxvi., p. 37.

oxygen, confirms M. Dumas' views experimentally. From the strong polarisation of light transmitted through the liquid oxygen, M. Pictet supposes the formation of crystals of solid oxygen.

Finally, M. Pictet announced that he also had succeeded in solidifying hydrogen under a pressure of 650 atmospheres, and $-140°$ of temperature. The jet of hydrogen was steel-blue in colour, perfectly opaque, and extended to a length of 4½ inches.

P. H.

The Berlin-Halle-Mainz Underground Telegraph Line.

(Dingler's Polytechnisches Journal, vol. ccxxvi., p. 363.)

This cable is composed of seven copper wires, of 0·63 millimètre diameter, instead of 0·60 millimètre, as in the Berlin-Halle cable. The conductor is protected with two layers of gutta-percha and Chatterton compound, the first layer of compound being upon the conductor itself, and the second between the two gutta-percha coverings. The conductor has a limit of resistance of 10·5 Siemens units at 15 Cent., and the insulation is above 500,000,000 Siemens units per kilomètre (1,093½ yards). The laying of the cable proceeded at such a rate that, starting from Halle on the 13th of March, Hohenthurm, 6 miles' distance, was reached by the 27th of March, Bitterfeld (19 miles) on the 4th April, Gräfenhainchen (29⅔ miles) on the 13th April, Wittenburg (43½ miles) on 27th April, and Potsdam (87 miles) on the 1st June, and 28th of June the chief telegraph office at Berlin (105½ miles) was in connection. The core of the cable is laid up in a 7-strand, which affords seven different lines of communication, the whole of the 7-cored cable being enclosed or encased in an iron wire sheathing, protected with two layers of hemp and an asphalt coating, as in the Halle-Berlin cable. The cable, coiled upon a drum, was paid out into an asphalt-filled trench; the drum, mounted on a wagon-carrier, revolving as the wagon proceeded. The cable was buried as uniformly as possible at a depth of 3·28 feet, at which depth it was considered that it would be free from injury by pressure or atmospheric influence. Where buried at a less depth a protective shield was employed, such as iron tubes or masonry, and the cable was protected against atmospheric and temperature effects by a packing of cotton or wool waste. When masonry was used, a gutter of 6 to 10 inches depth, and of 3 to 4 inches breadth, was formed, into which the cable was laid, packed in cotton waste or wool-waste, and covered for about 1 inch with pure sand or fine earth; the gutter was then filled with cement, and this cement was generally carried for above 2 inches over the masonry.

P. H.

The Telephone.

(Comptes rendus de l'Académie des Sciences, vol. lxxxv., pp. 776–777, 1023–1026.)

M. Breguet has presented to the Academy a short note descriptive of Professor Graham Bell's telephone, and this note subsequently elicited some remarks from other members of the Academy. M. Breguet points out that Professor Bell's telephone is an extremely simple apparatus. The voice of the person who speaks puts into vibration a small circular plate of thin sheet iron; this plate vibrating in the presence of a pole of a bar-magnet changes the magnetic distribution in the bar at each of its movements, and as a small bobbin of wire surrounds the extremity of the magnet, induced currents of an intensity corresponding to the amplitude of the vibrations are produced in the wire. These currents are received in the bobbin of an apparatus identical with the transmitting apparatus. They produce corresponding magnetic variations in its bar-magnet, and consequently vibrations in the iron plate situate before the magnet. These vibrations received by the ear produce sounds identical with those emitted into the first telephone. M. Breguet has corresponded through a circuit representing 621 miles of ordinary telegraph wire. A telephone taken to pieces and put together again without any particular care shows no great difference in its use; which proves the apparatus not to be very delicate, and capable of receiving all kinds of sounds.

M. Trouvé proposes a modification of Professor Bell's telephone, in which is substituted for the simple disk or plate a cubic chamber, each face excepting one constituted by a vibrating membrane. Each of these membranes when put into vibration by the same sound influences a fixed magnet furnished with an electric circuit. In this manner, by associating all the currents generated by the magnets, an intensity is obtained which increases proportionally with the number of magnets influenced. For the cube may be substituted a polyhedron.

P. H.

A Carbon Battery. By P. Jabloschkoff.

(Comptes rendus de l'Académie des Sciences, vol. lxxxv., p. 1052.)

Carbon burnt in steam-engines produces work which, transformed into electricity by means of magneto-electric machines, furnishes that electricity more economically than any battery dependent upon chemical action. This consideration led the Author to the idea of producing electricity by directly attacking carbon. To effect this, ordinary coke, as the positive, and platinum, as the negative electrode, were plunged into molten nitrate of soda or potash. Iron may be substituted for the platinum. The electro-

motive force of this battery varies between 2 and 3 units, Bunsen's battery being taken at a maximum of 1·8 unit. The most practical form of this battery does not necessitate the previous melting of the alkaline nitrate. A piece of the coke is ignited and put into contact with the nitrate in powder. Chemical action is then immediately set up, the temperature produced fuses the salt that surrounds the coke, and the battery continues in action. A cylindrical vessel of cast iron serves as the negative or unattacked electrode, and an iron wire basket contains the coke and acts as a rheophore.

P. H.

Rheostatic Machine. By G. Planté.

(Comptes rendus de l'Académie des Sciences, vol. lxxxv., pp. 794–796.)

Following the construction of his well-known secondary battery, the Author, by means of a cylindrical commutator charges a number of mica or other condensers in quantity or parallel arc, and discharges these, by revolving the commutator in tension or series. Weak dynamic electric charges can thus be made to produce somewhat powerful static effects. In connection with a secondary battery to charge a series of condensers arranged in this manner, a considerable number of discharges may take place without sensibly enfeebling the secondary battery, because each discharge removes only a very small quantity of electricity, and the battery circuit is never closed by a conductor. The electricity from the source simply disperses itself over the surfaces offered by all the condensers, where it is discharged as a spark by revolving the commutator.

P. H.

Winding Electro-magnets for Maximum Effect.

By R. S. Brough, Assoc. Inst. C.E.

(Proceedings of the Asiatic Society of Bengal, 1877, p. 134.)

Mr. Schwendler attacks this problem from the point of view of the resistance of the bobbin, but as this treatment involves an equation of the fourth order, the Author prefers to start from the thickness of the wire. This method also leads to a simple relation between the resistance of the electro-magnet and the external resistance. The case is taken of an elongated bobbin with straight sides and circular ends as a common form, and the results can be at once applied to circular bobbins by putting the length of the sides equal to nothing. Let Y = the magnetic effect of the bobbin, R = the resistance of the bobbin, S = external resistance, E = electromotive force of the battery, and n = the number of convolu-

tions. Then (Jacobi and Dub), $Y = \frac{n E}{R + S}$, and the problem is to make Y a maximum, treating the diameter of the wire with which the bobbin is wound as the independent variable, of which n and R are known functions. It is noted that the force exerted by a coil on a steel magnet is proportional to Y, whereas the force exerted on a soft iron armature is proportional to Y^2, but maxima occur in both cases, which are met by one solution. Let A = the outer diameter of the circular ends, a = the inner diameter, b = length of the bobbin, c = the length of the straight sides between the circular ends, δ = diameter of the wire, ρ = radial thickness of the insulating covering, and L = length of the wire on the bobbin. Then,

$$n = \frac{b\,(A - a)}{2\,(\delta + 2\,\rho)^2}$$

each wire being allowed a square the length of whose sides is equal to the diameter of the covered wire; and

$$L = \frac{b\,(A - a)}{2\,(\delta + 2\rho)^2}\left\{\frac{\pi\,(A + a)}{2} + 2c\right\}.$$

But $R = \lambda\,\frac{4L}{\pi\delta^3}$, where λ is the specific resistance between opposite faces of the unit cube of the conducting material; and substituting for L in this expression its equivalent as previously found, introducing a substitute for the reciprocal of Y, and differentiating, the value of δ which makes the magnetic effect is found:

$$\delta = 4\sqrt{\frac{\lambda b\,(A - a)}{\pi(1 + 2\mu)\,S}\,\{\pi(A + a) + 4c\}}$$

where $\frac{\rho}{\delta} = \mu$. This expression for δ contains η, itself a function of δ; but this difficulty is easily got over by supposing $\mu = 0$. The result of solving the equation is an approximate value of δ, namely, that which it would have, were there no insulating covering to the wire. $\eta = \frac{\rho}{\delta}$ is to be calculated with this approximate value for δ, and again δ with this value for μ. By repeating this process, which involves very little trouble if logarithms be employed, any desired degree of accuracy may be attained.

The expression for the resistance of the bobbin may be written

$$R = \frac{\lambda b\,(A - a)}{\pi\delta^4\,(1 + 2\mu)^2}\,\{\pi(A + a) + 4c\}$$

and supplying the value of δ^4 it is found that

$$R = \frac{1}{1 + 2\mu}\,S$$

from which, so long as μ not $= 0$, the resistance of the bobbin must always be less than the external resistance. Putting $\frac{\rho}{\delta}$ for μ, then

$$R = \frac{\delta}{\delta + 2\rho} S$$

which expresses the physical law, namely, that

$$\frac{\text{Resistance of bobbin}}{\text{External resistance}} = \frac{\text{Diameter of bare wire;}}{\text{Diameter of covered wire.}}$$

P. H.

Conditions of Maximum Magnetisation of Electro-magnets.

By T. du Moncel.

(Comptes rendus de l'Académie des Sciences, vol. lxxxv., p. 743.)

In former papers the maxima conditions of electro-magnets have been deduced from formulæ in which it has been supposed that the attractive forces were proportional to the squares of the intensities of the currents, to the squares of the number of turns or convolutions of the magnetising helix, to the diameter of the iron core, and to the square roots of their lengths. The Author doubts that these laws are applicable under all degrees of magnetisation, and he has already pointed out[1] considerable departures within certain limits as regards the diameter and length of core. He now finds this also the case with the law that represents the electro-magnetic forces as proportional to the squares of the intensities of the current. It has long been known that Joule, de Haldat, Müller, and Robinson have found that at the commencement of a current, and when the magnetic state of the iron is far removed from the point of saturation, the attractive force, instead of increasing as the square of the intensity of the current, increases in a much more rapid ratio, and that this ratio again diminishes near the point of saturation, remains for a short period stationary at this limit, and subsequently diminishes to that of simple proportionality to the current intensities. The question then arises, what should be the resistance of the magnetising helix with regard to the exterior circuit? The helices, the Author concludes, should always have less resistance than the exterior circuit, in the amount of half where g is taken as variable, and in the ratio of $2a + \frac{c}{a}$

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[1] "Comptes rendus," vol. lxxxv., pp. 377, 466, 481, 497 and 652.

to $a + c$ in the case where the variable is a. It is then to be concluded that on circuits where the interruptions of the current are multiplied, the resistance of the electro-magnets should be proportionally greater as the completions of the circuit are of shorter duration; and it is for this reason, as well as for faulty insulation, that Mr. Hughes has considerably reduced the resistance of electro-magnets employed on long circuits. On a line of 310½ miles, Mr. Hughes has found that the electro-magnets of his instrument should not have a resistance above that of 74½ miles of the line. Of course the imperfections of insulation conduce also to this diminution.

P. H.

The Influence of Heat and Light on the Electrical Conductivity of Selenium and some Metals.

From the following articles in the Annalen der Physik und Chemie, No. 12, 1877:—

"Ueber die Abhängigkeit der electrischen Leitungsfähigkeit des Selens von Wärme und Licht. Von W. Siemens." P. 521.

"Ueber den Einfluss des Lichtes auf den electrischen Leitungswiderstand von Metallen. Von G. Hansemann." P. 550.

"Ueber Dr. R. Börnstein's Photo-Electricität. Von G. Hansemann." P. 561.

The chief conclusions which the Authors have drawn are:—The light-sensitiveness of selenium is in the highest degree dependent on purity and molecular constitution, the least admixture with other metals reduces it. A proof of this is given by the statement that no light-sensitiveness was perceived in plates of selenium to which only ½ per cent. of silver had been added. The light-sensitiveness is in a great degree injured by strong light effect and by great heating or cooling, even when no variation of the conductivity of the preparation appears.

The property of increase or decrease of the conductivity, by the duration of illumination, appears, with differently prepared selenium, in very different results. This property has been found difficult to deal with, because the selenium by its changing from the amorphous to the crystalline condition on being heated above 100° C., gives so much lower conductivity, and so much slower increase of conductivity with the duration of illumination. In the first of the following series of experiments marked A, selenium plates, changed by immersion in a paraffin bath heated to 100° C. were used; whilst in the series marked B, plates were used which had been put into a paraffin bath and slowly heated up to 100° C., and then kept at that temperature for several hours. In these experiments the obscure heat rays were absorbed as much as possible by the light being passed through a glass trough filled with a solution of alum. The electric current was passed only during the measurements through the prepared selenium long

enough to allow of the mirror of the galvanometer arriving at its position of rest.

TABLE A. (MOD. I.)

The measurements were carried out with 12 Daniell's elements, which, on the entrance of the illuminating rays into the selenium plate, produced a deflection of 92° on the scale.

After minutes	..	2·5	5	10	15	20	25	30	35	40	45	50	55	60
Deflection	92	112	132	152	162	167	173	177	180	183	185	187	189	190
Light-effect	..	20	40	60	70	75	81	85	88	91	93	95	97	98
Differences	..	..	40	20	10	5	6	4	3	3	2	2	2	1

TABLE B. (MOD. I.)

The measurements were carried out with 50 Daniell's elements.

Time . . .	0′	5′	10′	15′	30′	1^h	2^h	3^h	4^h	5^h	6^h	7^h	7^h 30′
Deflection .	160	162	167	173	191	196	200	212	228	235	244	235	229
Light-effect .	..	2	7	13	31	36	40	52	68	75	84	75	69
Differences .	..	..	..	..	..	36	4	12	17	6	9	−9	−7

Quite a different behaviour presents itself on the duration of illumination of selenium plates which have been changed into the crystalline condition by being kept for some time at a temperature of 200° to 210° C. In table C, one Daniell's element was employed, and that each time only long enough for the deflection to arrive at its maximum, perhaps ten seconds, as the case might be. The non-illuminated plates gave a deflection of 35° on the scale.

TABLE C. (MOD. II.)

Duration of illumination . . .	10″	0^h 5′	0^h 10′	0^h 15′	0^h 20′	0^h 25′	0^h 30′	0^h 35′
Deflection through illumination . .	148	117	104	96	90	86	82	78
Differences . . .	148	−31	−13	−8	−6	−4	−4	−4
Duration of illumination	0^h 40′	0^h 45′	0^h 50′	0^h 55′	1^h	1^h 5′	1^h 10′	1^h 15′
Deflection through illumination . .	76	74	72	70	69	68	66	65
Differences . . .	−2	−2	−2	−2	−1	−2	−1	−1

After several hours' darkness, the deflection returned to 32° of the scale.

This experiment shows, that with both modifications a maximum of conductivity is attained. This maximum being attained, the light-effect diminishes, an occurrence that is termed the "fatigue" of selenium. How far this retrogression appears, even in Mod. I., has not been examined, because there is needed just as long duration for the diminution of the light-effect after attaining the maximum as there has been required for ascending to the maximum.

A consideration of the illumination experiments, represented by curves which are given, does not decide as to the influence of illumination on the electrical conductivities of the metals examined (gold, silver, aluminium, and platinum), although a variation of the resistances of the surfaces of the metals of about $\frac{1}{200}$ per cent. has been evident, but perhaps this has not occurred through the illumination.

The following numbers show the differences of the first and fourth deflections given by alternating illumination and non-illumination of platinum strips inserted in the current circuit:—

Non-Illumined.	Illumined.	Non-Illumined.	Illumined.	Non-Illumined.	Illumined.	Non-Illumined.	Illumined.
333·8	333·9	333·9	333·9	333·9	333·9	333·9	332·8
334·0	333·9	333·8	333·9	333·8	333·7	333·8	333·9

The mean for the illuminated as well as for the non-illuminated is 333·86.

The Authors have not, in any of their experiments, been able to confirm the opinion of Dr. R. Börnstein that light has influence on the electrical-conducting resistance of other metals than selenium, neither have they been able to notice any trace of what he terms a photo-electrical current.

P. H.

On the Influence of Heating upon the Galvanic Resistance of Hard-drawn Wires. By O. Chwolson.

(Carl's Repertorium für Experimental Physik, vol. xiv., pp. 1 to 27.)

The Author reviews previous researches by others into this subject. He finds that by heating to redness hard-drawn platinum-iridium wire its resistance diminishes about 3 per cent.; when extinguished, the resistance again increases slightly. The heating of the platinum-iridium wire is understood to be effected by the passage through it of a galvanic current. The heating to redness

of a hard-drawn zinc wire by means of a gas-burner diminishes its resistance about 2 per cent. Hard-drawn aluminium wire similarly heated diminishes in resistance about 2 per cent. Aluminium-bronze wire diminishes in resistance about 8 per cent., but increases about 3 per cent. on cooling. The resistance of palladium wire also diminishes by heating to redness, and again increases when extinguished. Silver-copper alloy of 82·9 per cent. silver and 13·4 per cent. copper diminishes in resistance as much as 12 per cent., and being extinguished returns to its original resistance. Steel wire heated to dull redness diminishes in resistance about 5 per cent., by further heating the reduction extends to 8 per cent., the resistance increases by cooling. With heating to dull redness iron wire diminishes in resistance, but only about 0·33 per cent.; with stronger heat it increases, and with still further heating surpasses the original value by 5 per cent. Each time of extinguishing increases the resistance. By heating to red heat hard brass wire is reduced in resistance more than 8 per cent.; by stronger heating the resistance is increased about 1 per cent.; quenching has the same effect. By heating to red heat hard-drawn copper wires diminish in resistance about 3 per cent.; extinguishing results in an increase of 0·5 per cent.; stronger heating increases the resistance until the initial value is even surpassed. By heating platinum wires to redness the resistance is diminished, but by stronger heating it increases, even passing the initial value; quenching increases the resistance. The same results obtain with German silver wire, but quenching diminishes the resistance. The resistance of lead wires increases by heating.

P. H.

Engraving on Glass by Electricity. By G. Planté.

(Comptes rendus de l'Académie des Sciences, vol. lxxxv., p. 1232.)

A plate of glass or section of crystal is covered with a concentrated solution of nitrate of potash by simply pouring the liquid upon the plate laid horizontally upon a table or in a shallow basin. In the liquid covering the glass along the edges of the plate is laid a platinum wire communicating with the pole of a secondary battery of fifty to sixty elements; touching the glass with another platinum wire forming the other electrode a design may be engraved upon the surface. The depth of the engraving can be varied by the rate of movement of the platinum point. Either electrode may be used as graver, but less current is necessary with the negative pole. Any source of electricity of sufficient tension may be employed, as a Bunsen battery of a large number of elements, or a Gramme or magneto-electric machine.

P. H.

The Precipitation of Copper by Electricity. By N. S. Keith.

(Engineering and Mining Journal, Nov. 17, 1877, p. 366.)

(A Paper read before the American Institute of Mining Engineers, at the Amenia Meeting, October, 1877.)

The Author was recently applied to by a firm engaged in the manufacture of crystallized sulphate of copper, from scrap copper, to report on the best method of recovering the remainder of the copper from the mother liquors, when these had become too impure to yield merchantable sulphate. The liquors to be treated contained an amount of sulphate of copper equivalent to 4½ per cent. of the metal, together with various proportions of sulphates of silver, nickel, tin, zinc, antimony, and iron.

The plan of depositing the copper by an electric current, produced either by a battery or by a dynamo-electric machine, was proved by a simple calculation to be too expensive; the cost, if a battery were employed (taking zinc at 12½ cents per lb.), being 60 cents per lb. of copper deposited, or with a magneto-electric machine, driven by a steam engine, about 14 cents per lb. (coal being $8 per ton).

The ordinary method of obtaining precipitated or cement copper from such a solution, by placing scrap iron in it, has the disadvantage that the copper deposited is chiefly in the form of a fine powder, mixed with insoluble basic sulphates of iron, and needing to be treated in a refining furnace, to remove the iron, before it can be used. It was found, however, that these objections might be entirely obviated, and the copper obtained in a pure coherent form, by carrying out the operation so as to prevent direct contact between the copper solution and the iron. For this purpose, the iron was placed in an ordinary porous cell, filled with a solution of sulphate of iron, free from copper, and this, with its contents, was placed in a larger vessel containing some of the copper solution and a sheet of metallic copper. On connecting the iron and the copper by a wire, external to the solutions, so as to establish an electric current, the deposition of the copper, and the solution of the iron, as sulphate, at once commenced, and in thirty-six hours the liquor was completely freed from copper, which was deposited on the copper sheet, as a beautiful velvet-like coat, pure and coherent. The amount of iron dissolved was only the equivalent for the copper deposited, namely, 56 of iron for 63·5 of copper.

After some further preliminary trials, eighteen large porous cells, 12 inches in diameter by 32 inches high, have been procured to contain the scrap iron and solution of sulphate of iron for carrying out the precipitation on a large scale, and these will be placed in large oil barrels, filled with the copper solution, and containing each a sheet of metallic copper, connected by a wire with the scrap iron in the corresponding porous cell.

The copper solution may be either filled separately into the barrels, and removed when exhausted, or they may be joined in series, and the liquor run in succession through as many as may be needed to complete the deposition of the copper. A low percentage of copper in the liquor increases the speed of exhaustion.

The only further attendance needed is for the addition of loose scrap iron to replace that dissolved, and the dilution of the iron solution when it approaches saturation. If the solution is of no value, some of it may be simply displaced occasionally, and allowed to flow over into the outer vessel, by pouring water into the cell.

In this way fine merchantable copper may be produced from copper solutions by one direct process, with inexpensive apparatus, and at a cost of 1 cent per lb. (£4 per ton of 2,000 lbs.), when scrap iron is worth $20 per ton.

W. H.

Industrial Electric Lighting. By M. Delahaye.

(Bulletin de la Société industrielle de Rouen, vol. v., pp. 286–306.)

The Author sketches the progress of electric lighting, and gives as the result of the practical lighting of the silk-mills of Mr. Powell the following conclusions:—Electric lighting by electro-dynamic machines and Serrin lamps is perfectly practicable, and entails no more inconvenience than gas. In the case of large halls of sufficient height the inclusive cost is about one-fifth that of gas. There is probability of improvement in some means that will yield more homogeneous carbons, and in systems by which the electric light may be subdivided into groups, each giving an illumination equal to that of 10 to 15 Carcel burners.

P. H.

Application of Leyden Jars to Electric Lighting. By P. Jabloschkoff.

(Comptes rendus de l'Académie des Sciences, vol. lxxxv., p. 1098.)

The Author has employed Leyden jars of large surface in order to distribute, at several different points, the current given by a single source of electricity, with a view to its application to lighting purposes. The machines employed have chiefly been those giving alternating currents, and the Author considers that the results obtained necessitate definition of the apparatus employed. The condensers are formed of large surfaces of metallic leaves separated by insulating leaves of grass, gutta-percha, &c. As the Author works with alternating currents, he does not condense

electricity for a certain time to produce an instantaneous discharge, and he cannot therefore term these apparatus condensers. Dr. Warren de la Rue employs the terms accumulator or excitator. One of the conductors from an alternating current machine is connected with one of the surfaces of Leyden jar apparatus, which in this case is termed an excitator. By the other surface of this excitator and the second conductor (or earth) a constant series of alternating currents is received. The second surfaces of the series of Leyden jars may give up the currents to a single conductor and single light focus, or the second surface of each of the series of jars may be connected to a separate conductor, each with a light focus. Experiment has shown that in the first case the current is superior to that given directly by the machine; in the second case the sum total of partial effects is also superior to the effect of the primitive current.

P. H.

Gas and Electricity.

(Journal für Gasbeleuchtung, vol. xx., pp. 431–444.)

This journal contains the statements of several speakers at a meeting of gas engineers in Leipzig. Herr Frischen draws attention to the use of the selenium-photometer. In this instrument a plate of selenium is employed to receive alternately the rays from a standard candle, and from the source of light the intensity of which is to be measured or to be compared with that of the standard. It is a property of selenium that its electrical resistance is modified by the action of light proportionally to the intensity of the light. The selenium plate is included in a galvanometric circuit with a small battery; the standard candle is adjusted on its distance-slide with regard to the selenium plate until the same galvanometric deflection is obtained when the selenium plate is exposed to the rays from the standard candle and to those from the source to be measured. The intensities of the lights are then inversely proportional to the square of their distances from the selenium plate. This instrument is the invention of Dr. Werner Siemens, and is described as compact, easily manipulated, and independent of the colour of the light.

Herr Oechelhäuser objects to the comparison of the electric light with gas-light, and points out that however well adapted the electric light may be to the illumination of works of a constructive character, shops and factories are still to be more economically lighted by gas.

P. H.

On the Rolling of Ships. By VICE-ADMIRAL BOURGOIS.

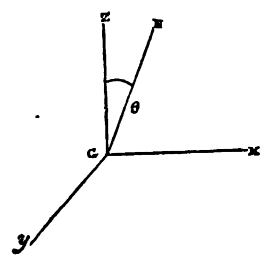
(Revue maritime et coloniale, vol. liii., p. 545, and liv., p. 5.)

The amplitude of a ship's roll when among waves is diminished by making her natural period greater than that of the waves. This principle can only be advantageously employed when the period of the ship can be made greater than that of the longest and slowest waves. As this cannot be done in small vessels, the Author investigates to what extent the received theories on the rolling of ships give results agreeing with those of experience, and also to what extent the results differ.

Consider the movements about three rectangular axes passing through the centre of gravity of the ship, the axis of x being longitudinal, that of y transverse, and that of z vertical.

The angular movements of the ship are, rolling about G x, pitching about G y, and yawing about G z. Rolling about her axis G x alone is considered, and in the case of unresisted still-water oscillations let G z be the vertical through G at the time t, and let G N be the original vertical through G making with G z an angle θ.

Let P be the weight of the ship, δ her metacentric height, and r



her radius of gyration about the axis G x, the equation of rolling is, therefore,

$$\frac{P}{g} r^2 \frac{d^2 \theta}{d t^2} + P \delta \sin \theta = 0;$$

integrating between the limits θ_0 and θ_1 there is obtained

$$P \delta (\cos \theta_1 - \cos \theta_0) - \frac{P}{2g} \left\{ \left(r \frac{d \theta_1}{d t} \right)^2 - \left(r \frac{d \theta_0}{d t} \right)^2 \right\} = 0,$$

which, by expansion of the cosines as far as two terms, and by replacing θ for θ_1, becomes

$$\frac{d \theta}{d t} = \pm \sqrt{\frac{g \delta (\theta_0^2 - \theta^2)}{r^2}};$$

taking the lower sign and putting m for $\sqrt{\frac{g\,\delta}{r^2}}$, then

$$\frac{d\,\theta}{d\,t} = -\,m\sqrt{\theta_0^2 - \theta^2}\,;$$

$$\text{or } \theta = \theta_0 \cos m\,t\,;$$

which gives T the period of an oscillation from port to starboard or *vice versâ* equal to $\frac{\pi}{m}$,

or $$T = \pi\sqrt{\frac{r^2}{g\,\delta}}.$$

After considering the subject of "resisted rolling," the Author discusses the movement of the centre of gravity.

Let s be the area of the plane of flotation, P the weight of the ship, p the heaviness of the water, and let F be the vertical resistance of the water on the ship due to her vertical oscillations through it, then the equation of motion is

$$F + \frac{P}{g}\frac{d^2 z}{d\,t^2} + s\,p\,z = 0.$$

The integration of this equation cannot in general be effected, as F is a function of t.

If $F = 0$ the equation of motion becomes that of a simple pendulum, the time of oscillation being $= \pi\sqrt{\frac{P}{s\,p\,g}} = \pi\sqrt{\frac{v}{s\,g}}$, where v is the immersed volume of the ship.

The only case in which the vertical travel of the centre of gravity has been experimentally ascertained is that of the "Elorn," a small vessel 82 feet 3 inches long, 16 feet 4 inches breadth of beam, and 6 feet 6¾ inches draught of water, and a displacement of 106 tons. This vessel was heeled over by being held away from a wharf by a horizontal beam hinged on the end abutting against the wharf, and meeting the ship in the vicinity of the water-line. A horizontal hawser was connected to the ship at some distance above the hinged beam, which when hauled upon served to give the vessel any required degree of inclination. The hawser and beam being simultaneously disengaged from the vessel, she was left free to oscillate.

Unfortunately, this means of inclining the vessel was not perfect. In nearly all cases the ship was slowly raised, when the hawser was hauled taut, by pivoting round the edge of the hinged beam. Consequently when the hawser was disengaged the vessel fell, and the first vertical oscillations were principally due to the initial circumstances and not to the rolling motion. The time of oscillation was very near, being a little in excess of, the result given by the equation $T = \pi\sqrt{\frac{v}{s\,g}}$, being 1·16 second for the first

oscillation, and 1·09 second for the others. After a fall of nearly $2\frac{1}{2}$ inches, the vessel rose generally only through $\frac{3}{4}$ inch or $1\frac{1}{4}$ inch, and then under the influence of some cause evidently external, such as the reaction of a wave, she nearly attained the height from which she had initially descended, and then recommenced her vertical oscillations in quite a regular manner, the period of which approached to that of the rolling oscillations without quite attaining it. In one experiment the centre of gravity started initially from a point not unduly elevated. In this experiment the oscillations presented a greater regularity without any of the disturbances referred to above. In several successive oscillations the centre of gravity rose to the height from which it started. The mean period of eight consecutive vertical oscillations was 1·75 second, which is very nearly a mean between the vertical period unaccompanied by rolling, viz., 1·09 second, and that of the rolling oscillations, viz., 2·33 seconds. In this experiment the vertical velocity of the centre of gravity was about $\frac{3}{4}$ inch per second, so that it may be reasonably inferred that even in the largest ships the vertical motion of the centre of gravity can have but little effect in reducing the amplitude of the roll.

If the element of the curve described by the centre of gravity of the ship in time $d\,t$ be represented by $d\,y$, the radius of curvature of this element of the curve by r_1, and the arc described in time $d\,t$ by $d\,\theta$, then

$$d\,y = r_1\,d\,\theta, \text{ or } r_1 = \frac{d\,y}{d\,\theta};$$

and therefore the axis of oscillation will be found by setting off along the normal to the curve described by the centre of gravity a length equal to $\frac{d\,y}{d\,\theta}$. This applies to all positions of the centre of gravity.

After discussing the question how to find the vertical displacement of the axis of oscillation during a period of rolling, the Author proceeds to consider resistance as the square of the angular velocity. If the resistance to rolling be supposed proportional to the square of the angular velocity, and also to the immersed area of the longitudinal vertical plane at any angle of heel, then if l be the length, p the immersed depth of the longitudinal vertical plane, and k a co-efficient of resistance, it is easy to obtain the equation

$$r_1\frac{d^2\,\theta}{d\,t^2} - \frac{k\,g\,l}{3\,\mathrm{P}}\left(\frac{d\,\theta}{d\,t}\right)^2\left\{(p - r_1)^3 - r_1^{\,3}\right\} = 0.$$

By putting $\frac{d\,\theta}{d\,t} = m\;\theta_0\;\sin\;\pi\;\frac{t}{\mathrm{T}}$ and reducing, there is obtained

$$r_1\cos\pi\frac{t}{\mathrm{T}} - \frac{k\,g\,l\,\theta_0}{3\,\mathrm{P}}\left((p - r_1)^3 - r_1^{\,3}\right)\sin^2\pi\frac{t}{\mathrm{T}} = 0.$$

By attributing different values to the elements of the ship this equation gives a series of values of r_1 corresponding to arbitrary values of $\pi \frac{t}{T}$. If $p = 2$ mètres (6·56 feet), and $\frac{k\,g\,l\,\theta_0}{3\,P} = 20$, which represents the case of the "Elorn" when inclined at about 30°, the value of r_1 will be found to increase rapidly with that of $\pi \frac{t}{T}$ until $r_1 = 0 \cdot 9$ mètre (2·9 feet), corresponding to $\frac{\pi t}{T} = 10°$; beyond this it approaches gradually to 1 mètre (3·28 feet), which it attains when the ship is upright; it increases slowly to 1·1 mètre (3·6 feet), as $\pi \frac{t}{T}$ increases to 150°. After $\pi \frac{t}{T} = 170°$, r_1 increases rapidly to infinity, showing that at the end of the oscillation the movement of the ship is nearly one of lateral translation. Thus r_1, with the exception of small intervals of time at the beginning and end of each roll, is nearly constant and equal to 1 mètre. There is reason to think that if other cases had been considered a similar result would have been arrived at.

Pendulum experiments carried out on the "Magenta," in 1863, showed that the axis of oscillation was a little more than 8 feet below the water-line, or about 5 feet below the centre of gravity of the ship. On board the "Armide" in 1869 similar experiments showed that the axis of oscillation was between 3 feet 3 inches and 5 feet 5 inches below the centre of gravity of the ship, which was itself 1 foot 1 inch below the water-line. On board the "Sybille" the axis of oscillation was found to be approximately midway between the plane of flotation and the keel. On the "Loire" experiments were made in 1876, which, when repeated again and again under the same conditions of wind and sea, always gave the same result as to the position of the axis of oscillation. When the experiments were made on several successive days under varying conditions of wind and sea, the axis of oscillation was found to be sometimes higher and sometimes lower. From a considerable number of these experiments it was ascertained that the higher positions of the axis of oscillation were caused by the smoother states of the sea, and the lower positions by the rougher states of the sea. The amplitude of the rolls had little influence on the position of the axis. The mean of all these experiments gave a position of 7 feet 1 inch below the centre of gravity of the ship. The limits of variations of the axis were 1 foot 6 inches above and below the mean position. These experiments made at sea by several observers, and under such varying conditions, all agree in placing the axis of oscillation of the ship at some distance below the line of flotation and the centre of gravity.

In analysing the rolling in still and resisting medium, the Author finds that the time occupied by the ship (in any one oscillation from one side to the other) in passing from the extreme

angle of heel to the upright position is greater than the time expended in passing from this position to the other extreme of the roll.

The main results of these experiments may be summarised as follows:—

(1) That the time of oscillation does not vary, sensibly, with the amplitude.

(2) That the time occupied by the ship in righting herself from the extreme angle of heel is greater than the time occupied in completing the roll.

(3) Period of oscillation increases with resistance.

(4) This period is sensibly greater than that due to the moment of inertia of the ship herself.

Effect of False Keels and Bilge Keels.—To test the practical effect of bilge keels two experiments were made on the "Elorn." In one experiment she had two bilge keels 30 feet long by 20 inches deep, in the other the vessel was without bilge keels. The difference in the moment of resistance was 50·85 foot-tons in favour of the bilge keels; this corresponds to a pressure of about 31 lbs. per square foot on the bilge keel, which is more than twice the resistance of a thin plane moving normally to its surface. M. Bertin has also made experiments on a lighter with almost precisely the same results. Hence it may be concluded that, in round numbers, the moment of resistance due to bilge keels is not less than that due to a resistance of 30 lbs. per square foot acting at their centres.

Effect of Forward Motion on Resistance to Rolling.—From special experiments made by M. Bertin to ascertain whether the co-efficients of extinction derived from experiments when the ship is not under way applied to the case when she is going ahead, it appears that a certain vessel had a co-efficient of extinction of ·0109 when not going ahead, and this became ·0123 at 4 knots, and ·0150 at 8 knots; this seems reasonable if it be borne in mind that in going ahead the vessel is constantly acting on new masses of water.

S. T.

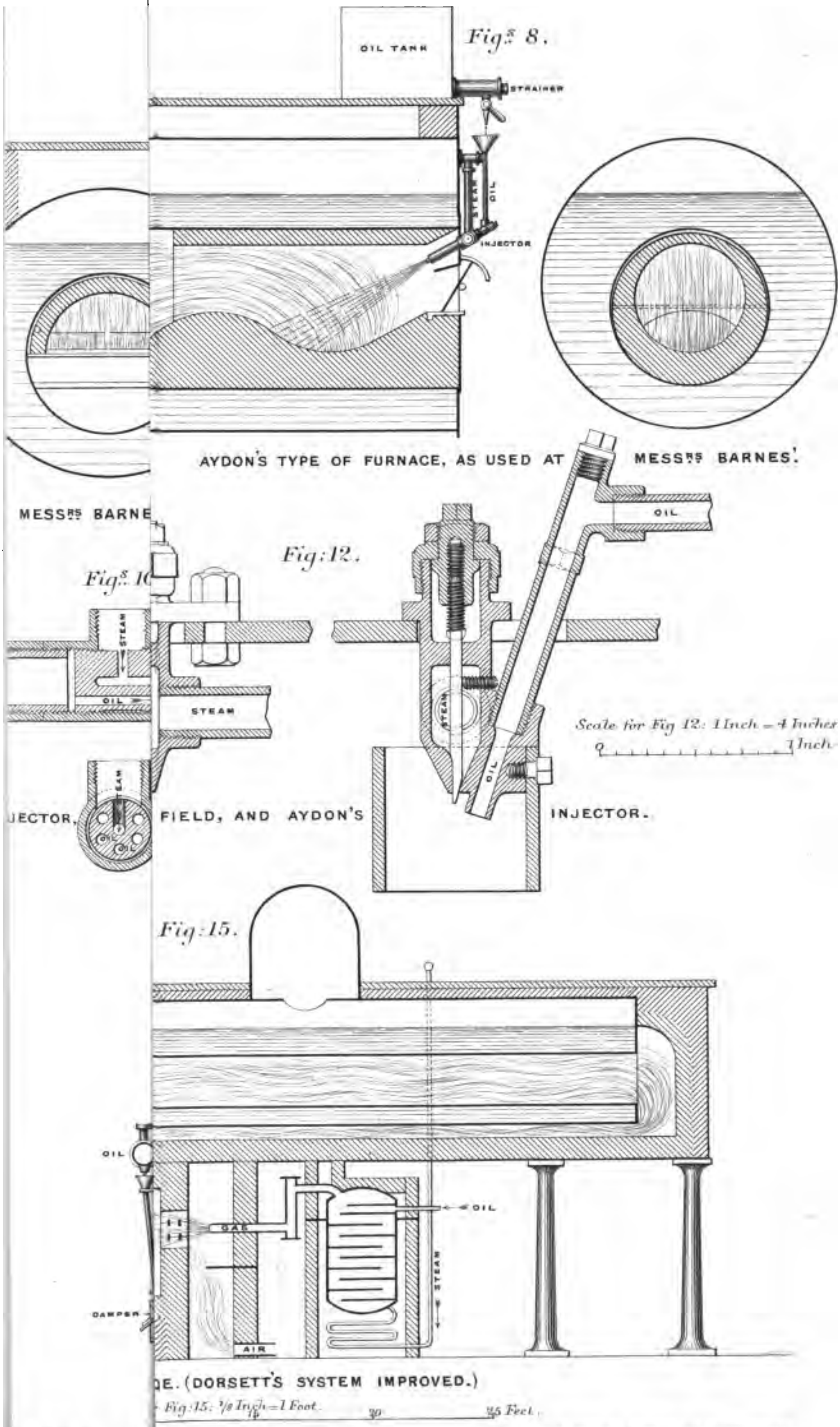
INDEX

TO THE

MINUTES OF PROCEEDINGS,

1877-78.—Part II.

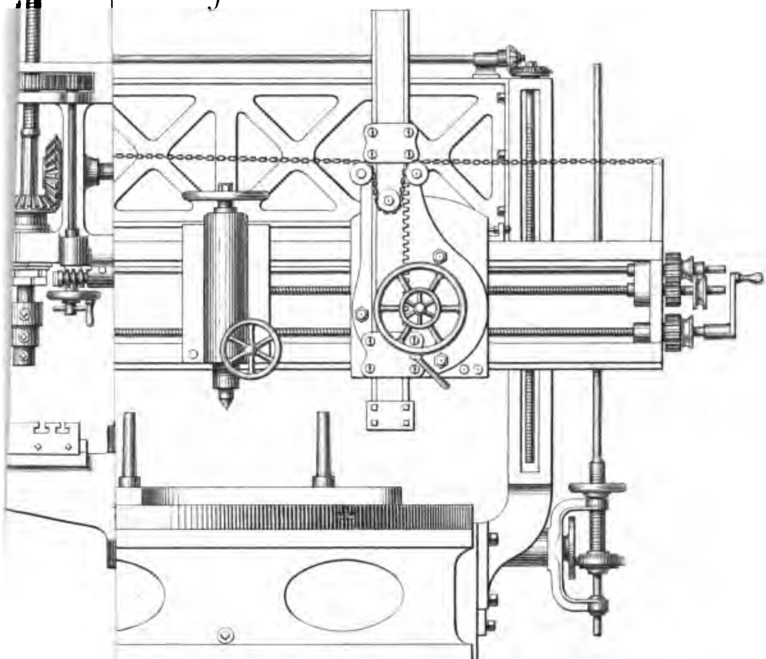
END OF VOL. LII.



THOS KELL, LITH 40, KING ST COVENT GA

PLATE. 5.

Fig: 11.



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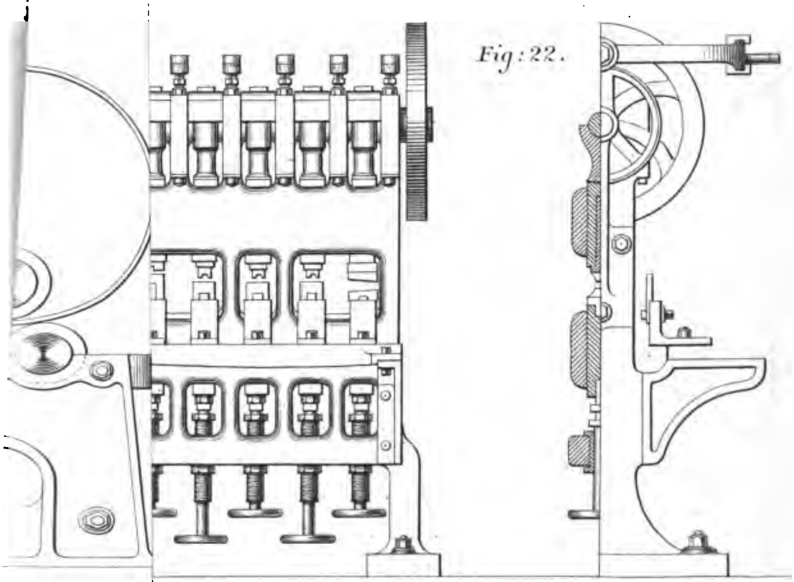
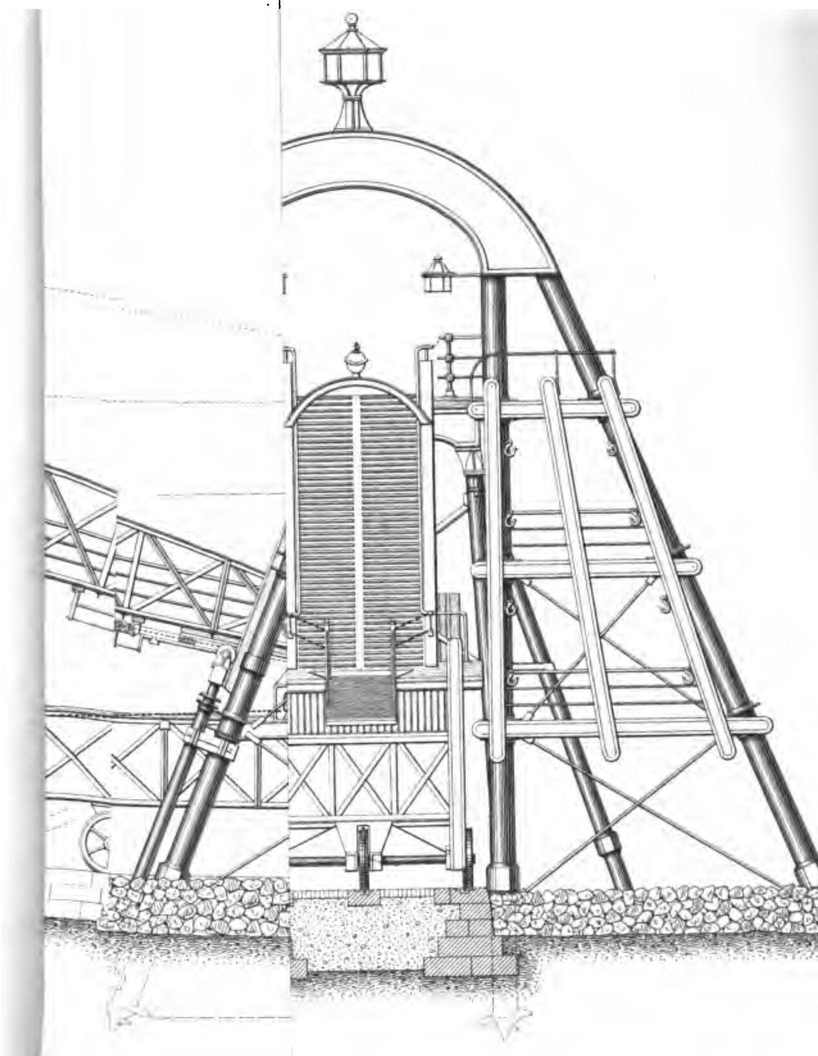


15 Inches. 15 Feet.

THOS KELL, LITH. 40, KING ST COVENT GARDE



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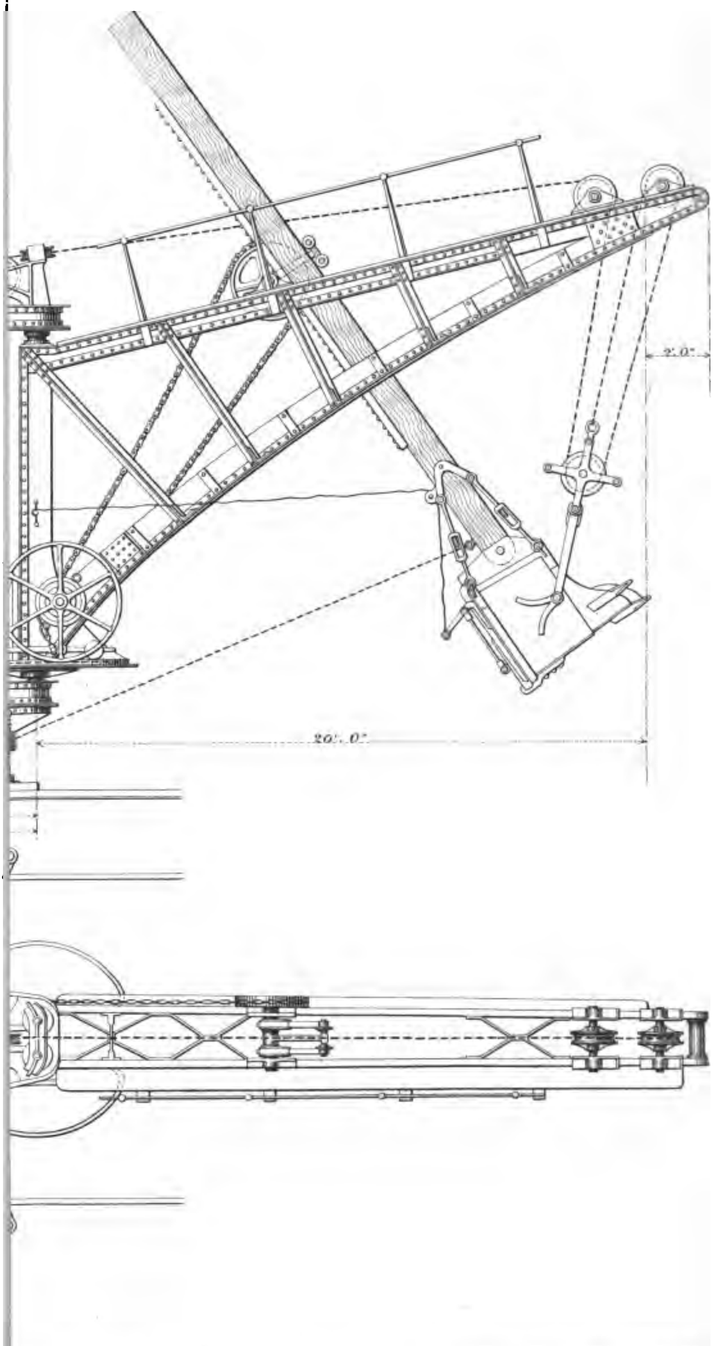
THOS KELL, LITH 40, KING ST COV


2'. 0".
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